ALBERTA TIER 2 SOIL AND GROUNDWATER REMEDIATION GUIDELINES

Alberta
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

PART A: OVERVIEW OF ALBERTA GUIDELINES AND IMPLEMENTATION FRAMEWORK

1. INTRODUCTION

1.1 Alberta's Framework for the Management of Contaminated Sites

Alberta's framework for the management of contaminated sites is designed to achieve three policy outcomes:

- **Pollution prevention**: Avoid "impairment of, or damage to, the environment, human health or safety, or property".
- **Health protection**: Take action on contaminated sites that is commensurate with risk to human health and the environment.
- **Productive use**: Encourage remediation and return of contaminated sites to productive use.

Under this framework, three management options are provided: Tier 1, Tier 2, and Exposure Control. Within a given land use, sites will fall into a range of sensitivities because of differences in receptors and site conditions. Tier 1 remediation guidelines are generic; that is, they are developed to protect the more sensitive end of the range and can therefore be used at most sites without modification. The Tier 2 approach allows for the consideration of site-specific conditions through the modification of Tier 1 guidelines and/or removal of exposure pathways that may not be applicable to the site. Exposure Control involves risk management through exposure barriers or administrative controls based on site-specific risk assessment. These management options are described in more detail in Section 3. The management framework is outlined in Figures 1 through 4.

The Tier 1 approach has been described in detail in the *"Alberta Tier 1 Soil and Groundwater Remediation Guidelines"* (AENV, 2007a). The Tier 1 approach is based on the assumption that all exposure pathways and receptors relevant to a particular land use are actually present. At Tier 1, exposure pathways that are part of the generic scenario for the applicable land use may not be screened out. Under Tier 2 it may be possible to screen out certain exposure pathways and/or modify the Tier 1 guidelines on the basis of site conditions. This companion document describes how the Tier 2 approach might be used to develop remediation objectives for a site.

There are two options available under Tier 2 remediation guideline development, namely modification of the generic Tier 1 guidelines or development of site-specific remediation objectives. This document briefly describes both options and gives specific details related to modification of generic Tier 1 guidelines. Development of site-specific remediation objectives requires more detailed planning and a more detailed site-specific ecological and human health risk assessment than are described in this document. For this option, more interaction with Alberta Environment is expected and only general principles are provided in the Tier 2 document.

This document is divided into two parts. Part A consists of an overview of the tiered framework and provides guidance for proceeding through the assessment and decision processes at each tier, as well as considerations and requirements related to the implementation of risk management strategies. Part B contains prescriptive guidance for developing Tier 2 remediation objectives by modification of Tier 1 guidelines, including eligible exposure pathways, parameter adjustments, data requirements and calculation procedures. Detailed guidance on the development of Tier 2 objectives through site-specific risk assessment is beyond the scope of this document.

1.2 Tier 1 and Tier 2 Levels of Protection

The objective of the Tier 1 and Tier 2 soil and groundwater remediation guidelines is to deliver the same degree of human health and ecological protection, regardless of which option is used. The same protocols are used to develop both Tier 1 and Tier 2 guidelines. The two options differ in the amount of site-specific information used to develop the guidelines.

The Tier 1 remediation guidelines are simple tabular values that require minimal site information for their use. Conservative assumptions about soil and groundwater characteristics have been used to develop the Tier 1 guidelines to protect sites likely to be sensitive to contamination. In this way, less sensitive sites under the applicable land use are also protected. Some site information is needed to ensure that site conditions are adequately represented by the assumptions used to develop the Tier 1 guidelines. Those sites that may be more sensitive than conditions assumed in the Tier 1 guidelines are more appropriately dealt with under the Tier 2 approach.

Applying Tier 2 guidelines typically requires more information from the site than Tier 1 guidelines. This additional information allows the assessor to develop guidelines that are tailored to the particular characteristics of the site. When a site has characteristics that make it more sensitive than the Tier 1 assumptions, the resulting Tier 2 guidelines may be more restrictive than Tier 1 values. Sites that are less sensitive may have Tier 2 guidelines that are less restrictive than Tier 1 values, but which deliver the same level of human and ecological health protection because they are tailored to that specific site.

In keeping with Alberta Environment's requirement for the same level of human or ecological protection, human health and ecological protection endpoints must be maintained at all management Tiers. Changes to the endpoints require ongoing administrative controls or site management and therefore would be considered under Exposure Control. When adverse effects are evident, contaminants must be managed to alleviate adverse effects, regardless of whether a site meets Tier 1 or Tier 2 remediation guidelines.

1.3 Relationship to Other Guideline Documents

This is a companion document to the *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2007a) and should be used in conjunction with that document as

guidance for the determination and implementation of site-specific remediation objectives for the management of contaminated sites.

Two documents provide the protocols and the primary technical basis for the risk-based guidelines calculated in this volume:

- For all compounds except petroleum hydrocarbons: *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines*. (CCME, 2006a); and,
- For petroleum hydrocarbons: *Canada-Wide Standards for Petroleum Hydrocarbons (PHCs) in Soil*. (CCME, 2007a).

2. ALBERTA ENVIRONMENT POLICY ON CONTAMINATED SITE MANAGEMENT

This section provides an introduction to the guiding principles that underlie Alberta Environment policy on the management of contaminated soil and groundwater. These principles and the associated policy provide a framework for implementing the three contaminated site management options: Tier 1, Tier 2, and Exposure Control.

2.1 Pollution Prevention

Pollution prevention is a critical factor in maintaining a healthy environment. Alberta Environment policy strongly emphasizes the importance of proactive efforts that keep soil and groundwater clean and free of contaminants rather than relying on remediation after contamination has occurred. Remediation programs are often costly and, in the case of large and complex contaminant releases, may not be capable of fully restoring the quality of contaminated land or water, leading to a loss of land or water use options. Soil and groundwater contamination may be prevented or minimized by exercising care and control through:

- proper siting of facilities and chemical storage areas
- secondary containment of potential contaminants
- regular inspections and maintenance of tanks and pipelines
- soil and groundwater monitoring programs
- early source identification and removal or management; and,
- proper waste disposal and management

2.2 Legislation

Two key acts, the *Environmental Protection and Enhancement Act* (Government of Alberta, 2006), and the *Water Act* (Government of Alberta, 2000) form the legislative basis of Alberta Environment's policies on the management of contaminated soil and groundwater.

2.2.1 *Environmental Protection and Enhancement Act*

Regulatory requirements related to substance release, remediation and reclamation are found in the *Environmental Protection and Enhancement Act* (EPEA). The purpose of the EPEA (Government of Alberta, 2006) is "to support and promote the protection, enhancement and wise use of the environment". The EPEA allows the Minister to establish guidelines and objectives.

Substance Release Provisions

The EPEA prohibits the release of substances in an amount that causes or may cause a significant adverse effect. "Release", "substance", and "adverse effect" are defined in the EPEA. The release of a substance to the environment can occur rapidly (as in the rupture of a vessel containing the substance) or over a longer period of time (as with a gradual

leak from an underground pipe that goes undetected). When a substance is released that causes an adverse effect or, for releases after Sept. 1, 1993, has the potential to cause an adverse effect, the release must be reported. Remedial measures must be implemented whenever a release causes, or has the potential to cause, an adverse effect. Additional guidance on release reporting can be found in *A Guide to Release Reporting* (AENV, 2005a) and *Informational Letter 98-1* (EUB, 1998).

Remediation Certificates

The EPEA authorizes the Director or inspector to issue remediation certificates where contaminated land has been remediated. While encouraging remediation of contaminated land, the remediation certificate also protects the responsible party from future environmental protection orders related to the remediated release.

Conservation and Reclamation

The EPEA includes requirements for the conservation and reclamation of specified land. Specified land is defined in the EPEA and the *Conservation and Reclamation Regulation* (Government of Alberta, 1993; C&R Reg.). The EPEA and the C&R Reg. require reclamation of specified land to equivalent land capability. Equivalent land capability is defined in the C&R Reg. With respect to soil contamination on specified land, the *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2007a) establish generic remediation guidelines for achieving equivalent land capability. Site-specific guidelines for achieving equivalent land capability can be developed using a Tier 2 approach.

2.2.2 *Water Act*

Water is a public resource, and is owned and regulated by the Government of Alberta. Regulatory requirements, related to the management of water supplies and water quality (including groundwater quality), are found in the *Water Act* (Government of Alberta, 2000). The purpose of the *Water Act* is "to support and promote the conservation and management of water, including the wise allocation and use of water". The *Water Act* allows the Minister to establish guidelines for water management.

2.3 Principles of Contaminant Management

A contaminant is a substance that is present in an environmental medium in excess of natural background concentration (CCME, 2006a). Three key elements of Alberta's framework for the management of contaminated sites: source control, contamination delineation, and contaminant management, including remediation.

2.3.1 Source Control

A source of contamination is anything that adds contaminant mass to the environment. Source control is a necessary action in support of pollution prevention, a key outcome of Alberta's policy on contaminated site management. If there is evidence of soil or groundwater contamination, the source, if it is still present, must be identified. Sources must be removed or controlled as soon as practicable.

Contaminants can be introduced into the environment in a number of ways. Leaking pipelines and storage tanks are common sources of contamination. Contaminated soil and groundwater may be a source of contamination to other areas of a site if the contaminants are mobile. Removal or management of these sources is a necessary part of contaminated site management. Soil or groundwater with naturally elevated substance concentrations may become a source of contamination if it is redistributed and causes the receiving soil or water to exceed Tier 1 or 2 remediation guidelines. This can be avoided by proper characterization and handling of soil and groundwater prior to redistribution. Failure to control sources allows contaminants to spread, increasing risk and remediation costs, and potentially limiting future land use if remediation to Tier 1 or 2 guidelines is not possible.

Where complete source removal is not feasible, the source must be removed to the extent possible and treatment, control, and/or management measures must be implemented to address the residual source. Treatment measures will assist in the ongoing reduction of source contaminant concentrations. Source control measures must prevent the contaminant from spreading to adjacent areas, causing the soil or groundwater there to exceed Tier 1 or 2 guidelines. If source control measures are required, they must operate until the source meets Tier 1 or 2 remediation guidelines. Source control must be supported by a monitoring program that demonstrates its efficacy.

Where source control rather than source remediation is implemented, a site is considered to be managed through an Exposure Control approach rather than a Tier 1 or Tier 2 approach.

2.3.2 Delineation

When soil or groundwater is found to contain contaminants in excess of Tier 1 or 2 soil or groundwater remediation guidelines, a delineation program must be implemented. The delineation program must identify both the horizontal and vertical extent of contaminant concentrations exceeding the Tier 1 guidelines or the Tier 2 guidelines derived by the pathway exclusion approach (Section 5.2 and Table 5 in this document). Adequate delineation provides information needed to support appropriate decisions about contaminant remediation and management. Delineation programs must be extensive enough in both horizontal and vertical directions to allow all applicable exposure pathways and receptors to be properly assessed. Delineation is complete when measured concentrations are less than Tier 1 or 2 remediation guidelines. Complete delineation can be accomplished prior to undertaking remediation or when confirmatory samples are taken to show that remediation is complete.

2.3.3 Contaminant Management

When the volume of soil or groundwater containing contaminant concentrations that exceed Tier 1 or 2 guidelines is completely delineated, a plan must be developed to remediate or otherwise manage the contaminants in a manner that is consistent with the framework outlined in Section 3.

2.3.4 Management of Contaminants in Subsoil

In general, Alberta Tier 1 surface soil remediation guidelines apply to all soil and groundwater, regardless of depth. However, subsoil guidelines for salinity and petroleum hydrocarbons may be used at Tier 1 under the following circumstances:

Salinity

Topsoil guidelines for electrical conductivity and sodium adsorption ratio must be applied to the L, F, H, O, and A horizons (Soil Classification Working Group, 1998) or equivalent surficial material where these horizons are not present. Subsoil guidelines may be applied below the A horizon or equivalent in lieu of topsoil guidelines. Further information is available in the *Salt Contamination Assessment and Remediation Guidelines* (AENV, 2001c).

Petroleum Hydrocarbons

Surface soil guidelines for petroleum hydrocarbon fractions F1 to F4, benzene, toluene, ethylbenzene, and xylenes must be applied to a depth of 1.5 metres. Subsurface guidelines may be used as follows:

- Below 1.5 metres in depth within a 5 metre setback from an oilfield wellhead (see Municipal Affairs and Housing Advisory Land Use Planning Notes on Abandoned Wellsites), or
- below 3 metres in depth at any site.

The Tier 1 approach allows the exclusion of the ecological direct contact pathway for soil and groundwater for petroleum hydrocarbon fractions F1 to F4 for any land use below a depth of 3 metres. All other exposure pathways apply. Consistent with the *Canada-Wide Standard for Petroleum Hydrocarbons in Soil* (CCME, 2007a), exclusion of the ecological direct soil contact pathway is permitted below 3 metres with the application of "management limits" for petroleum hydrocarbon fractions that represent maximum concentrations that apply at any depth. Management limits for petroleum hydrocarbon fractions F1 to F4 are noted in Appendix A in the *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2007a).

2.4 Soil Protection in Alberta

Soil is a resource that supports important ecosystem functions. As a society, we rely on our soil resources to supply food and fibre, purify water, degrade waste materials, maintain healthy forests and grasslands, and provide a structural foundation for urban and rural buildings and infrastructure. As stewards of our soil resource, we have a responsibility to manage our activities in a way that sustains the ecological functions of soil. At sufficient concentrations, soil contamination can impair the ability of soil to support important ecosystem functions as well as pose risks to human health. Care must be taken to prevent soil contamination and, when a substance release occurs, prompt actions must be taken to remediate or otherwise manage the release. Maintenance of good soil quality will ensure that soil fulfills its ecological role and will maintain our land use options as Alberta continues to grow and diversify.

2.4.1 Using Tier 1 or Tier 2 Soil Remediation Objectives

The goal of the Tier 1 soil remediation guidelines is to provide numerical targets for remediation of contaminated soil. To ensure consistency with "pollution prevention", a key outcome of Alberta's contaminated sites management framework, the Tier 1 soil remediation guidelines are **not** "pollute-up-to" levels. Sources must not be left uncontrolled until cumulative releases result in an exceedance of Tier 1 or 2 soil remediation guidelines. This results only in further contamination, increased remediation costs, and potential loss of land use options. Source control is a crucial component of pollution prevention.

While the Tier 2 approach may not define the same guidelines as outlined in Tier 1, the objectives at Tier 2 remain consistent with Tier 1. Human health and ecological protection endpoints must be maintained in keeping with Alberta Environment's requirement for the same level of human and ecological protection at all tiers of management. Therefore, the principles outlined in this section apply regardless of whether a Tier 1 or Tier 2 approach is employed to manage the site.

2.4.2 Background Soil Quality

The background concentration of a substance in soil is the natural concentration of that substance in the absence of any input from anthropogenic activities or sources. In some situations, the background concentration of some substances can be a significant proportion of, or even exceed, the Tier 1 guidelines (AENV, 2007a). In cases were the natural background is demonstrated to be greater than Tier 1 guidelines, the remediation level shall be to natural background or to guidelines developed using Tier 2 procedures.

Background concentrations will vary with soil parent material, soil depth, and hydrologic regime. These factors lead to spatial variations in background concentrations that may or may not be predictable. To gain a good understanding of background conditions at a site, it is necessary to take sufficient representative samples from soils with similar characteristics to the affected site, but which are taken from outside the area affected by contamination. Sample depth and landscape position, soil profile characteristics and parent material should be recorded for all samples.

Care should be taken to distinguish between apparent background concentrations that are the result of diffuse anthropogenic sources, and true, natural background conditions. In comparing against background, emphasis should always be placed on ensuring that anthropogenic sources are not identified as natural background.

2.4.3 Land Use

Potential receptors and their exposure to soil contaminants are affected by land use. For example, workers on an industrial site experience a different exposure than a toddler living on a residential property. Different ecological receptors are found in a forest setting than on an urban commercial property. Tier 1 soil remediation guidelines are calculated for five types of land use: natural areas, agricultural, residential/parkland, commercial, and industrial. These land use types may not correspond exactly to the range of municipal zoning options, but by evaluating the types of receptors and exposure

conditions used in calculating the guidelines for each land use scenario, it is possible to identify which land use scenario is protective for a particular municipal zoning requirement. Assessors must determine the full range of uses allowed under the applicable zoning bylaw when determining the appropriate land use for Tier 1 application. Where a municipal zoning decision incorporates more than one land use scenario, the most conservative land use must be applied. More detailed guidance on land use may be found in Section 3.2.

In some cases, a contaminated site may be adjacent to a property with a more sensitive land use. Even though contaminant concentrations may meet appropriate guidelines for the less sensitive land use, mobile substances may migrate to the adjacent property at concentrations that exceed guidelines for the more sensitive land use. This is a particular risk for the vapour inhalation pathway and the groundwater direct ecological contact pathway. When a contaminated site is bordered by a more sensitive land use, the vapour inhalation guidelines (soil and groundwater) and the groundwater direct ecological contact guideline for the more sensitive land use apply to the contaminated site anywhere within 30 m of the more sensitive property boundary (see Figure 5).

2.4.4 Relationship to Air and Water Quality

Soil contamination interacts with air through volatilization and with water through dissolution and leaching to groundwater or runoff to surface water. Mobile soil contamination that adds contaminant mass to air or water is automatically considered a source. Therefore it must be remediated, or the contaminant release from the soil must be controlled as noted in Section 2.3.1.

For all land uses except natural areas, the Alberta Tier 1 soil remediation guidelines include soil concentrations that have been developed to protect indoor air quality. When soil contaminant concentrations exceed the soil remediation guideline protective of indoor air, then management of this exposure pathway is required. In this case, three options are available (see Sections 4 and 6 and Table 5):

1. Remediate soil and groundwater to Tier 1 guidelines,
2. Conduct a more detailed site investigation, develop an alternate Tier 2 guideline and remediate to that guideline value, or
3. Ensure that the pathway is managed through exposure control until the risk is acceptable.

The Alberta Tier 1 soil remediation guidelines also include soil concentrations that have been developed to protect groundwater quality. When soil contaminant concentrations exceed the soil remediation guideline protective of any groundwater-governed pathway (e.g., protection of potable groundwater for drinking water, protection of groundwater for freshwater aquatic life, or other groundwater pathways), then an investigation of groundwater quality is generally required unless the groundwater pathway can be excluded under a Tier 2 approach. A groundwater quality investigation is also strongly recommended when contaminant concentrations in soil are close to the groundwater protection guidelines because the presence of preferential flow paths can result in

contaminants reaching groundwater even when general soil conditions appear not to pose a risk. It is also possible that mobile substances have leached out of the vadose zone into groundwater if sufficient time has elapsed since the release event.

Three options are available if the Alberta Tier 1 guidelines for the protection of groundwater are breached:

1. Remediate soil and groundwater to Tier 1 guidelines,
2. Conduct a more detailed site investigation, develop an alternate Tier 2 guideline and remediate to that guideline value,
3. Some pathways may be screened out based on lateral offset distances (e.g. freshwater aquatic life – Table 5), or if there is an isolating soil layer between the contamination and a Domestic Use Aquifer (Appendix E). If exposure pathways are excluded on this basis, the Tier 2 remediation guideline can be selected from the next most protective value in the relevant Tier 1 tables (AENV, 2007a – Appendices A & B), or
4. Develop exposure control mechanisms though site-specific risk assessment (Section 6).

2.4.5 Relationship to Land Application of Organic Materials and Industrial By-Products

The *Industrial Release Limits Policy* (AENV, 2000) specifies that substances regulated by Alberta Environment should be managed to prevent soil contamination. Under this policy, Alberta's approach to the management of wastes, industrial byproducts, composts, and other materials is based on the potential to improve soil quality. Wastes that provide no benefits to soil quality must not be applied to land in a manner that causes soil contamination. Industrial byproducts, composts, and other materials that provide a potential benefit to soil quality may be applied to land according to good agronomic or forestry practices and in accordance with any other regulatory requirements. Even when benefits can be shown, any potential contaminants in the byproduct must be managed to prevent their buildup in soil to concentrations that exceed Tier 1 or Tier 2 guidelines. Soil is a biologically active medium and is sometimes used as a treatment medium for soil contaminated by biodegradable substances. Land treatment of soil contaminated by gasoline, diesel fuel, jet fuel and kerosene is allowed if registered in accordance with the *Code of Practice for Land Treatment of Soil Containing Hydrocarbons* (AENV, 2005b).

Tier 1 guidelines are used to evaluate chemical concentrations in soil. They can also be used to evaluate chemical concentrations resulting from the mixing of industrial by-products or organic materials into soil. They should not be used to evaluate concentrations in the by-product or organic material itself, unless the material will be placed directly on land without being mixed with soil.

Tier 1 pesticide guidelines have been developed for a limited number of exposure pathways for which sufficient information is available. These values are intended for use

in the remediation of pesticide-contaminated sites and not for restricting pesticide use in accordance with registered application rates.

Disposal and treatment of wastes generated by the upstream oil and gas industry are regulated by the Alberta Energy and Utilities Board in accordance with Directive 50, *Drilling Waste Management* (EUB, 1996a) and Directive 58, *Oilfield Waste Management Requirements for the Upstream Petroleum Industry* (EUB, 1996b). Directive 50 Equivalent Salinity Guidelines (AENV, 2007b) can be used to assess and remediate drilling waste disposal areas for reclamation certification.

2.5 Groundwater Protection in Alberta

2.5.1 Alberta's Initiatives to Protect Water Resources

Water is a public resource, and is owned and regulated by the Government of Alberta. Alberta is facing pressures on its water resources as a result of population growth, drought, and agricultural and industrial development. In response to these stresses, the Alberta Government in collaboration with Albertans developed *Water for Life: Alberta's Strategy for Sustainability* (Government of Alberta, 2003). *Water for Life* is a comprehensive strategy for addressing water management concerns for the future that emphasizes knowledge and research, partnerships, and water conservation. The protection of groundwater and surface water quality is a key element in the *Water for Life* approach.

The three primary goals of *Water for Life* are ensuring:

- a safe, secure drinking water supply,
- healthy aquatic ecosystems, and
- reliable, quality water supplies for a sustainable economy.

Groundwater has many beneficial uses and an important role in drinking water, the economy and supporting healthy aquatic ecosystems. Approximately 25 percent of Alberta's population depends on groundwater, and groundwater is used in a wide variety of industrial and commercial activities. Groundwater discharges into surface water bodies, such as rivers and wetlands, supporting aquatic ecosystems. Because groundwater and surface water are integrally connected, groundwater cannot be managed in isolation from surface water and aquatic ecosystems.

A key element of *Water for Life* is the protection of water resources. In the protection of groundwater quality, the strongest emphasis is placed on preventing groundwater resources from becoming contaminated. However, where contamination of this valuable public resource has resulted in an exceedance of Tier 1 or 2 guidelines, it must be remediated or managed to ensure on-going protection of human health and the environment, and the restoration of beneficial uses.

This document provides a framework to guide how contaminated groundwater should be managed in Alberta. It differs from the companion Tier 1 document (AENV, 2007a) in that it provides a method to determining Tier 2 risk-based remedial objectives to indicate

when groundwater quality has been restored to an acceptable level, where the Tier 1 document provides generic risk based remedial objectives that may be applied to the majority of sites in Alberta.

2.5.2 Protection of Domestic Use Aquifers

Groundwater for domestic use is a significant current and future resource distributed over large geographic ranges in Alberta. Consequently, there is a need to protect the quality of Domestic Use Aquifers (DUAs).

The definition of a DUA is dependant on the amount of water an aquifer can produce, rather than the quality of the water in the aquifer, recognizing that technological treatment methods exist that can reduce or remove natural background substances. Furthermore, an aquifer does not have to be currently used for domestic purposes in order to be classified as a DUA, as the intent is to define and protect these aquifers for current and future use. Alberta Environment may consider any body of groundwater above the Base of Groundwater Protection[1] that is capable of a sufficient yield of water to be a DUA.

For the purpose of selecting and applying a groundwater guideline for human health protection by ingestion, a DUA is defined as a geologic unit (either of a single lithology or inter-bedded units) that is above the Base of Groundwater Protection having one or more of the following properties:

- A bulk hydraulic conductivity of 1×10^{-6} m/s or greater and sufficient thickness to support a sustained yield of 0.76 L/min or greater; or
- Is currently being used for domestic purposes; or
- Any aquifer determined by Alberta Environment to be a DUA.

While it is possible that peat deposits and muskeg may meet the definition of a DUA, based on hydraulic conductivity and unit thickness, Alberta Environment does not consider peat deposits or muskeg to be a DUA because groundwater in them is unlikely to be used as a domestic source.

The DUA drinking water pathway **cannot** be excluded using the Tier 1 approach. However, using the Tier 2 approach, it is possible to screen out the DUA drinking water pathway under certain circumstances, such as if there is an isolating unit meeting specific properties, or if the only reason a geologic unit meets the definition of a DUA is the presence of a shallow large diameter well.

For specific guidance regarding implementation, determining the sustained yield or exclusions allowed within this definition, see Appendix E.

[1] The Base of Groundwater Protection is the depth above which groundwater is naturally non-saline, having a natural concentration of total dissolved solids that is less than or equal to 4000 milligrams per litre. Information on the Base of Groundwater Protection is available from the Alberta Geological Survey.

2.5.3 Using Tier 2 Groundwater Remediation Guidelines

The goal of the Alberta groundwater remediation guidelines is to provide numerical targets for the remediation of contaminated groundwater. To ensure consistency with "pollution prevention", a key outcome of Alberta's framework for contaminated sites management, the Tier 1 groundwater remediation guidelines are **not** "pollute-up-to" levels. Sources must not be left uncontrolled until cumulative releases result in an exceedance of Tier 1 or 2 groundwater remediation guidelines. This results only in further contamination, increased remediation costs, and potential loss of water use options. Source control is a crucial component of pollution prevention.

2.5.4 Background Groundwater Quality

The background concentration of a substance in groundwater is the natural concentration of that substance in a particular groundwater zone in the absence of any input from anthropogenic activities or sources. In some situations, the background concentration of some substances can be a significant proportion of, or even exceed the Tier 1 remediation guideline. Remediation of groundwater to below background conditions is not feasible and is not required. Accordingly, it is important to have a good understanding of background groundwater conditions at a site.

Background concentrations will be specific to the groundwater zone being considered, and will vary both spatially and temporally. To gain a good understanding of background conditions at a site it is necessary to consider groundwater quality data from several monitoring wells installed in the zone of interest, located up- or cross- gradient from any contaminant sources. The more time-series data that are available, the better the understanding of background conditions will be.

Care should be taken to distinguish between apparent background concentrations that are the result of diffuse anthropogenic sources, and true, natural background conditions. In comparing against background, emphasis should always be placed on ensuring that anthropogenic sources are not identified as natural background.

2.5.5 Relationship to Soil, Air and Surface Water Quality Guidelines

Environmental media are interconnected. Contaminants in soil may leach into pore water or groundwater. Volatile compounds in groundwater may volatilize at the water table and can migrate through the soil into the interior space of buildings above. Soluble contaminants in groundwater can be transported laterally with the groundwater flow, and potentially enter a surface water body (creek, slough, lake, etc.) at the point of groundwater discharge.

Alberta Tier 1 groundwater remediation guidelines are developed to protect indoor air quality, plants and soil invertebrates, and water quality for a range of uses. Guidelines to protect a particular water use are calculated based on the corresponding water quality guideline (drinking water, aquatic life, irrigation, or livestock or wildlife watering).

Under the Alberta Tier 2 approach, it is possible to use site-specific information to evaluate risk to groundwater receptors. More details are provided in Sections 4 through 6.

As a minimum, this approach will involve a more detailed delineation and collection of site-specific information to support the Tier 2 decision. Generally, under the Tier 2 approach, site-specific information is used to more closely assess the risk of the substance interacting with the receptor of concern. Receptor reference values representing a safe level of exposure (e.g. drinking water, aquatic life guidelines, toxicity reference values etc.) are not open to modification under the Tier 2 approach.

2.5.6 Points of Compliance

For the purpose of this document, a point of compliance is the spatial location in an aquifer at which a groundwater quality guideline must be achieved to protect human and ecological receptors, to protect a groundwater resource, or to meet other conditions such as industrial use or groundwater management guidelines.

At one extreme, the compliance point could be established at the point of exposure such as a drinking water well (human-ingestion) or a river (ecological-aquatic life). However, this would imply that there could be deterioration in the quality of the groundwater between the contaminant source and the receptor, which could be judged unacceptable in terms of legislative requirements and/or restriction of potential future use of a groundwater resource. At the other extreme, a precautionary approach could set the groundwater compliance point directly beneath the contaminant source. This is likely to result in a more stringent remedial target concentration and may be unnecessary, as certain exposure pathways may be irrelevant at that particular location, the contaminated groundwater may never reach a receptor, or contaminants may be significantly attenuated in groundwater prior to reaching the exposure point.

To address both conditions, some fundamental principles are used to guide decisions for setting groundwater remediation guidelines and compliance points on individual sites in Alberta.

A DUA, as defined in Section 2.5.2, is an important current and future groundwater resource and must be protected to the maximum extent possible. The compliance point for the human health water ingestion pathway is everywhere within a DUA.

Groundwater aquifers can be an important current or potential future agricultural groundwater resource used for livestock watering and irrigation. For livestock watering, the compliance point is everywhere within the relevant livestock watering aquifer existing below agricultural or other grazing land. For irrigation, the compliance point is everywhere within the irrigation-use aquifer, where applicable.

Ecological receptors must be protected at key exposure points. For aquatic life or wildlife receptors, the minimum point of compliance is at the point of groundwater discharge into a surface water body that is capable of supporting an aquatic ecosystem. Groundwater guidelines are calculated to achieve this. Therefore, the groundwater at all points of groundwater discharge immediately adjacent to the aquatic water body must meet the aquatic surface water quality guideline. For terrestrial receptors (plants and soil invertebrates), the point of compliance is everywhere within the shallow groundwater

zone (i.e. the extent of groundwater less than 3 m below ground surface) and at the point of ground surface discharge.

Some additional information on how the point of compliance is used at Tier 2 or under exposure control options is discussed in Part B of this document.

2.5.7 Risk Management

Alberta's policy for risk management at contaminated sites has been implicitly reflected in various remediation guidelines developed and implemented in the province since 1991, including: the *Subsurface Remediation Guidelines for Petroleum Storage Tank Sites* (Alberta MUST Project, 1991; AEP, 1994); the *Alberta Soil and Water Quality Guidelines for Hydrocarbons at Upstream Oil and Gas Facilities* (AENV, 2001a); the *Risk Management Guidelines for Petroleum Storage Tank Sites* (AENV, 2001b); and the *Salt Contamination, Assessment and Remediation Guidelines* (AENV, 2001c). The underlying framework for most of these guidelines was the three-tiered model originally established by CCME in support the National Contaminated Sites Remediation Program.

There are two main "tracks" for the management of risks at contaminated sites in Alberta, namely remediation to risk-based objectives and exposure control. Remediation could be conducted in accordance with generic objectives, as outlined in *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV 2007a). Alternatively, one may employ modified risk-based remediation objectives as outlined in this document. Exposure control could involve the use of physical and/or chemical exposure barriers, administrative controls, or other forms of exposure management as outlined in section 6 of this document. Under this policy, exposure management will by its nature lead to conditions or restrictions, which would preclude regulatory closure.

Section 6 also outlines requirements for regulatory and stakeholder input and agreement, and lists other fundamental requirements independent of risk, including source control, mitigation of offsite contamination, odours, safety and nuisance conditions, and the requirement that EPEA not be contravened.

3. ALBERTA FRAMEWORK FOR THE MANAGEMENT OF CONTAMINATED SITES

3.1 Implementation Framework and Management Levels

The general framework for the management of contaminated sites in Alberta has three options and is illustrated by the flowchart presented in Figure 1. A more detailed framework specific to site management under the Tier 1 approach is presented in Figure 3. A brief description of the framework is provided below; a detailed discussion of the management and technical aspects of the Tier 1 guidelines is presented in subsequent sections of the document.

Under the Alberta framework, three options are provided for the management of contaminated sites as the proponent proceeds from initial site assessment to regulatory closure. The three options are:

- Tier 1 - generic remediation guidelines.
- Tier 2 - site-specific remediation guidelines based on the modification of Tier 1 guidelines.
- Exposure Control - risk management through exposure barriers or administrative controls based on site-specific risk assessment.

Regardless of the option chosen, the target level of human health and ecological protection afforded by Tier 1, Tier 2, or Exposure Control is the same.

As discussed below, regulatory closure is available for sites managed to achieve Tier 1 and Tier 2 remediation guidelines. This means that no conditions are imposed on future use of the site, within a given land use. The three management options are briefly described in the following paragraphs:

<u>Tier 1 - Generic Remediation Guidelines</u>

Generic guidelines are based on identification of the receptors to be protected under various land uses, the applicable exposure pathways, and a corresponding set of parameters that allow reasonably conservative predictions of risk at sites throughout Alberta. Whenever possible, models that incorporate toxicity information, receptor characteristics, and fate and transport mechanisms are used to derive Tier 1 guidelines. Risk-based assessments have not been completed for fluoride, sulphur, antimony, beryllium, boron, cobalt, molybdenum, silver, and tin. The Tier 1 guidelines for these compounds are based on professional judgment. Other compounds have been evaluated for only a limited number of exposure pathways. Where site assessments identify the presence of other influential exposure pathways related to these substances, Tier 2 guidelines may need to be developed.

Tier 1 guidelines are expected to be applicable to the majority of contaminated sites in Alberta, although site managers may choose a Tier 2 approach to incorporate more site information in the development of remediation guidelines. There may be some situations where site conditions result in a *more* sensitive scenario than is captured by the

conservative generic scenarios (e.g., a site underlain by very coarse sand and gravel with a high hydraulic conductivity). Information on situations where Tier 1 is not applicable is provided in Section 5.1.6 of the *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2007a). In such cases, a Tier 2 or Exposure Control approach will be required. Where the Tier 2 approach is required under Section 5.1.6 (AENV, 2007a), it can be restricted to the specific pathway/receptor relationships that are in question. Even at sites that eventually use a Tier 2 or Exposure Control approach, Tier 1 guidelines are normally used for an initial screening as the first step in a phased site assessment.

The Tier 1 process comprises an initial site assessment and characterization followed by the selection of the applicable Tier 1 guidelines. If feasible and appropriate, remediation management to Tier 1 guidelines will be undertaken. When a proponent believes Tier 1 remediation management is not feasible and/or appropriate, the proponent may proceed to the Tier 2 process or, in some cases, to Exposure Control. The use of Tier 1 guidelines is described in *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2007a).

Tier 2 – Modified Generic Remediation Guidelines

There may be circumstances where site-specific conditions modify potential human and ecological exposure, relative to the generic conditions used to derive Tier 1 guidelines, such that the generic guidelines are unnecessarily conservative. Alternatively, site-specific conditions may increase risks to a level that renders a Tier 1 approach unacceptable. Accordingly guidance is provided in Part B of this document on methods under which Tier 1 guidelines can be adjusted to a particular site, including a discussion of parameters for which generic values could be replaced by site-specific values. This guidance is summarized in Section 4.

There are three options that can be applied at Tier 2.

1. Modifying the Tier 1 guidelines based on exclusion of exposure pathways and receptors that may not be operable at the site. This approach is discussed in Section 5 and Part B of this document.
2. Adjusting the Tier 1 guidelines using site-specific values for certain parameters determined as part of a more detailed site assessment. The same models and approaches are used as for the development of the Tier 1 guidelines and a limited range of parameter adjustments to these models is allowed based on site-specific conditions. This approach is discussed further in Section 4 and Part B of this document.
3. Site-specific risk assessment as discussed in Section 5 of this document.

Sites where major adjustments to parameters or models are needed may require site-specific ecological risk assessment and/or human health risk assessment to develop appropriate remediation objectives. Quantitative risk assessment is a complex process with intensive data requirements. Complex risk assessments that do not require restrictions to the typical activities considered under a given land use and do not require ongoing risk management may be acceptable for regulatory closure under the Tier 2

process. However, these sites may have additional assessment, monitoring, and/or regulatory requirements that are beyond the scope of this guidance document.

Exposure Control - Risk Management

Exposure Control relies on ongoing risk management to control risks to human health and the environment. This management option is used for sites that require restrictions to the typical activities considered under a given land use or require ongoing risk management. While this option is available for management of risk at contaminated sites, it is not eligible for regulatory closure that is available under Tier 1 and Tier 2 approaches.

Some information on Exposure Control is provided in Section 6. Detailed guidance on site-specific risk assessment and Exposure Control options are beyond the scope of this document.

3.2 Land Use Definitions

For the purpose of developing and implementing soil and groundwater remediation guidelines in Alberta, five generic land uses have been defined – natural areas, agricultural, residential/parkland, commercial and industrial. A generic land use scenario is envisioned for each category based on typical activities on these lands. The five land uses are defined for the purpose of this document only. Where allowable land uses, as defined by a given jurisdictional authority, differ from those noted here, an assessment of allowable receptors and potential exposure pathways must be made to ensure consistency with assumptions based on definitions here. Where a more sensitive receptor or exposure pathway is allowed, the more sensitive land use description must be used in selecting the appropriate Tier 1 guidelines. Assessors must determine the full range of uses allowed under the applicable zoning bylaw when determining the appropriate land use for Tier 1 application. For most sites in Alberta, one of the five generic land use scenarios should be applicable. If none of the generic land uses are applicable, a site-specific Tier 2 approach will be required. The five land uses are defined as follows:

Natural Areas

Natural areas are defined as being away from human habitation and activities, where the primary concern is the protection of ecological receptors. Accordingly, human exposure pathways are not considered, with the exception of the protection of groundwater for drinking water pathway that, based on the definition of a DUA (Section 2.5.2 & Appendix E), applies in all land uses. Much of Alberta's forested land will fall into natural areas land use. Forested lands that are specified as grazing leases represent a special case that requires an amendment to the normal exposure scenario for natural areas. On such grazing leases, the livestock soil ingestion and protection of groundwater for livestock pathways must be addressed in addition to the regular pathways considered under natural areas land use. Natural areas land use must not be applied to areas that may reasonably be expected to be developed, such as those near municipalities and permanent dwellings.

Agricultural Lands

On agricultural land the primary land use is growing crops or tending livestock as well as human residence. This also includes agricultural lands that provide habitat for resident and transitory wildlife and native flora. To allow unrestricted future use of the land, a farm residence is assumed to be present anywhere on agricultural land.

Residential/Parkland

The primary activity on residential/parkland is residential or recreational activity. This land use includes campground areas and urban parks, but not wildlands in provincial parks, which are considered natural areas. Where urban parks are frequented by wildlife, wildlife exposure pathways should be addressed.

Commercial Land Use

On commercial land, the primary activity is commercial (e.g., shopping mall) and all members of the public, including children, have unrestricted access. Commercial land use includes day-care centres, buildings for religious services, hospitals, and medical centres. Commercial land does not include operations where food is grown directly in impacted soil on the site. Such operations would fall under agricultural land use.

Industrial Land Use

Industrial land is land where the primary activity is the production, manufacture or construction of goods. Public access is restricted and children are not permitted continuous access or occupancy.

3.3 Groundwater and Surface Water Use Definitions

Soils are hydrologically linked to groundwater and surface water systems. One of the objectives of Alberta's soil remediation guidelines is to manage soil-to-groundwater pathways to prevent unacceptable transfer of contaminants from the soil, which may ultimately affect groundwater and surface water use. Alberta's groundwater and surface water quality guidelines are representative of allowable chemical concentrations in groundwater or surface water at the point of compliance (see Section 2.5.6).

Alberta guidelines have been developed for four generic uses of groundwater or surface water affected by groundwater discharge:

- human consumption (potable water);
- aquatic life;
- livestock and wildlife watering; and,
- irrigation

These water uses are linked to land uses through the definitions of the generic land use categories. Other water use categories, for example recreation, as well as variations in water use within a defined land use category, may be addressed using the Tier 2 process.

3.4 Protection of Human Health and Ecological Receptors

In general, Alberta Environment follows the principles as outlined in *A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines* (CCME, 2006a).

The Tier 2 guidelines outlined in Part B of this document are sufficient to make simple adjustments to Tier 1 guidelines based on single source/receptor pathway considerations and small modifications based on simple changes to model parameters. Where generic input parameters or equations in this document differ from CCME (2006a), this document governs generic input values for model parameters.

For more complex site-specific risk assessments, the proponent must consider all aspects of the CCME (2006a) protocol. Exposure pathways and receptors described in this document and the choice of ecologically relevant receptors for the development of generic guidelines will need to be reconsidered to ensure that the most sensitive and relevant receptors have been captured and appropriately assessed for the site-specific assessment.

3.4.1 Protection of Human Health

Human receptors and exposure pathways

In keeping with CCME (2006a), guidelines need to be based on a critical human receptor that represents the most sensitive receptor to the substance and the most critical health effect within the land use scenario. In addition, the entire range of activities associated with the land use must be free of appreciable health risks.

The most sensitive receptor is a function of the receptor characteristics, the degree of potential exposure, the exposure pathway(s) and the chemical(s) of concern. In some instances, it may be necessary to identify the presence of uniquely sensitive receptors that may not be protected by the generic guidelines. Further guidance is available in CCME (2006a).

At Tier 1 and Tier 2, the general public is assumed to be present on agricultural, residential/parkland and commercial land. The general public is considered to incorporate all age classes and the most sensitive pathway/receptor combination must be used in establishing the appropriate risk-based guideline. At industrial sites, only adults are assumed to be present, which precludes the use of the child exposure model parameters. Human exposure is assumed to be inconsequential in natural areas, except where underlying groundwater is considered to be a potential source of drinking water. Where these definitions differ from the potential uses of a site, the risk assessment must be modified to consider the most sensitive case.

The following human exposure pathways are considered, as a minimum in the derivation of Tier 1 and Tier 2 remediation objectives where appropriate to the defined land use (based on CCME, 2006a):

- Direct contact with contaminated soil (soil ingestion, dermal contact with soil, inhalation of soil and soil-derived particulate)
- Ingestion of groundwater or surface water (potable water scenario)
- Inhalation of vapours migrating into indoor air
- Ingestion of produce, meat and dairy products.

More detailed descriptions regarding specific considerations under each of these categories can be found in derivation of human health and environmental endpoints from CCME (2006a). Information on the application to the Natural Area land use may be found in the companion Tier 1 document (AENV 2007a).

Human health protection endpoints

The human health protection endpoint is the same at all tiers of contaminated site management, and is expressed in terms of an allowable exposure level at which the likelihood of a receptor experiencing adverse health effects is essentially negligible. Specifically, the level of human exposure to a threshold chemical or non-carcinogen must not exceed the tolerable daily intake specified by Health Canada or other appropriate regulatory agency, considering also background exposure to the chemical. For a non-threshold chemical or carcinogen, the incremental lifetime cancer risk must not exceed 1 in 100,000 (1×10^{-5}), the value considered by Health Canada to be essentially negligible (Health Canada, 2004b).

3.4.2 Ecological Protection

Ecological receptors and exposure pathways

Risk-based remediation guidelines are required to fulfill two main goals from the ecological standpoint: protection of ecological receptors expected to be present at a site based on the setting and land use, and preservation of an appropriate level of ecological function of the site and its ecosystem components.

This document provides general guidance on how to develop remediation guidelines for protection of ecological receptors. More detailed protocol descriptions can be found in CCME (2006a).

A first step in developing risk-based remediation guidelines for ecological protection is to determine the ecological components potentially at threat from a substance release. Ecological receptors at a typical contaminated site, within the range of generic land uses considered in the development of the Alberta guidelines, span a range of trophic levels including soil-dependent organisms (plants, soil invertebrates and crops), soil function (e.g. nutrient and energy cycling, related microbial activities), and higher order consumers (terrestrial and avian wildlife and livestock). In addition, based on the potential for groundwater underlying a site to discharge to a surface water body, aquatic receptors including invertebrates, fish and waterfowl are considered. Receptors assigned to each land use for the purpose of guideline derivation must be sufficiently sensitive to capture effects to species most at threat from contaminated soil or food sources for the defined ecological use.

The following ecological exposure pathways are considered in the derivation of remediation objectives at Tier 1 and Tier 2 where appropriate to the defined land uses (based on CCME, 2006a):

- Soil contact with plants and invertebrates
- Soil and food ingestion by livestock and wildlife, including secondary and tertiary consumers
- Soil nutrient cycling processes
- Protection of surface water sustaining aquatic life
- Protection of groundwater and surface water used for livestock watering
- Protection of surface water used for wildlife watering
- Protection of groundwater and surface water used for irrigation

In addition, there may be other ecological considerations that must be considered on a site-specific basis. More detail on this can be found in CCME (2006a).

Ecological protection endpoints

Ultimately, ecological protection endpoints must be chosen to provide assurance that the ecological function will sustain activity within a given land use function (CCME 2006a). Ecological protection endpoints are the same at all levels of management, subject in some cases to a reduced requirement for ecological function based on land use.

Protection of ecological receptors is based on ensuring that exposure does not exceed appropriate toxicological benchmarks. At higher trophic levels, these benchmarks are based on designated chronic effects levels derived for specific species at the population level; for plants and soil invertebrates the benchmarks are determined and applied on an ecosystem basis through the use of species sensitivity distributions. A lower level of ecological functioning allowed at commercial and industrial sites is addressed by means of a less stringent protection level for plants and soil invertebrates.

3.4.3 Considerations other than toxicity

For complex risk assessments or where major changes to generic endpoints, models or pathway/receptor relationships are proposed, factors other than toxicity must be considered in the risk assessment.

Contaminants may have adverse effects in addition to producing toxic responses in human and ecological receptors. These may include aesthetic concerns (e.g. offensive odours), explosive hazards or damage to utilities and infrastructure. If there is evidence that a contaminant may cause significant effects beyond toxicity to human and ecological receptors, then this evidence should be evaluated.

Certain contaminants may potentially degrade into more toxic or more mobile chemicals (e.g., degradation of trichloroethylene to vinyl chloride). Since degradation rates are

affected by site-specific factors, potential for these types of effects and degradation products must be considered when developing Tier 2 remediation objectives.

3.5 Conditions and Restrictions Associated with Tier 2 and Exposure Control

The Alberta soil and groundwater remediation guidelines and implementation framework are intended to provide the same high level of protection of human health and the environment at all levels or tiers of site management. For Tier 1, this is ensured by the use of relatively conservative assumptions in the derivation of the risk-based numerical guidelines, such that the values can be applied to the large majority of sites within a land use category without condition or restriction. In other words, the normal activities associated with a particular land use are protected without the need for ongoing management of the site or of contaminants that may be present. Alberta Environment will provide regulatory closure for a site complying with the Tier 1 guidelines, unless site conditions are unsuitable for their application (see Part B, Section 2 of this document).

Management under Tier 2 guidelines delivers the same level of health and environmental protection by incorporating site-specific data into the development of appropriate remediation guidelines. Sites remediated to Tier 2 guidelines are eligible for regulatory closure.

Certain types of site-specific data or assumptions dictate the need for ongoing site management to ensure that the assumptions used to assess human and ecological risks or to develop site-specific objectives remain valid. Ongoing management of a site, or of the contaminants present, will generally invoke a land use restriction or condition that will preclude regulatory closure. Therefore site-specific adjustments or assumptions that would trigger ongoing management requirements can only be implemented under the Exposure Control option.

To avoid the need for ongoing management and, hence, possible conditions and land use restrictions, Tier 2 adjustments are usually limited to parameters that are measurable and stable, such as soil properties, geological conditions, hydrogeology and distances to natural surface water bodies. Tier 2 assessments that involve full site-specific risk assessment using models and assumptions that may differ from those used in the calculation of the Tier 1 guidelines may be accepted provided they do not require any form of ongoing risk management. Parameters that are unique to current site use, an existing development or the location of a receptor, such as the characteristics of a site building or the distance to a water well, may change in the future thereby invalidating the site-specific assumptions. An adjustment of such parameters is not allowed at Tier 2. In some cases exposure pathways may be inoperative under a particular site use (e.g. direct human or ecological contact with contaminated soil at a commercial site that is paved or capped) or the frequency of exposure may differ from the generic assumptions. Preservation of these conditions would require ongoing management; therefore these adjustments cannot be made at Tier 2. Further guidance on parameters and assumptions eligible for adjustment at Tier 2 is provided in Section 4 and Part B of this document.

4. OVERVIEW OF TIER 2 MANAGEMENT

Management under the Tier 2 approach involves modifying Tier 1 remediation guidelines while preserving equivalent human health and ecological protection endpoints. The process for developing, assessing and implementing Tier 1 soil and groundwater remediation guidelines is described in detail in the companion document *Alberta Tier 1 Soil and Groundwater Remediation Guidelines* (AENV, 2007a).

The process for Tier 2 management at contaminated sites in Alberta is illustrated schematically in the central portion of Figure 1 and in Figure 3.

Tier 2 remediation guidelines may be derived where adjustments to Tier 1 parameters or models are simple and based on stable, measured site-specific physical parameters. This approach is referred to as Guideline Adjustment, as illustrated in Figure 3. Technical requirements for Tier 2 Guideline Adjustment are provided in Part B and the Appendices to this document.

Complex sites or more complex monitoring situations where measured parameters are not stable or readily determined generally require site-specific ecological or human health risk assessment to develop appropriate Tier 2 remediation objectives. This approach falls under the Site-Specific Risk Assessment (SSRA) category. Prescriptive technical requirements for Tier 2 SSRA are beyond the scope of this guidance document. Proponents opting for Tier 2 SSRA should contact Alberta Environment to discuss the proposal and to establish the necessary regulatory requirements in these site-specific instances.

4.1 Conditions Triggering Tier 2

The decision to proceed to Tier 2 or Exposure Control management of a contaminated site is based on a number of possible triggers related to site-specific conditions.

Firstly, the use of Tier 1 guidelines would be precluded when site-specific land and/or water use does not conform to a generic land or water use category, when site-specific factors invalidate the modeling used in the derivation of the generic guidelines, when a higher degree of exposure than considered in generic scenario could result in more stringent guidelines, or when receptors may be more sensitive than considered in the default scenario and therefore result in more stringent guidelines. More detail on these exceptions are provided in section 5.1.6 of the companion Tier 1 document (AENV 2007a). They are summarized as follows:

- Source of volatile contaminants present within 30 cm of a building foundation
- Unique building features, including earthen floors or unusually low air exchange rates
- Sensitive receptors that are present but not accounted for in the generic Tier 1 land use description

- Groundwater flow to stagnant water bodies
- Soil or groundwater contamination present within 10 m of a surface water body
- Very coarse textured materials enhancing groundwater or vapor transport
- Contamination in fractured bedrock
- Contaminant source length parallel to groundwater flow greater than 10 meters
- Organic soils

Secondly, the assumptions used to derive the generic guidelines may be conservative relative to site-specific conditions, such that less stringent guidelines could be developed based on site-specific assumptions without reducing the level of human health and environmental protection.

The condition described above may also lead to the need for a more detailed risk assessment or Exposure Control option that may be beyond the scope of this document. Examples of site-specific conditions necessitating more detailed risk assessments include: parameters that are not readily determined, or are ineligible for adjustment (described in Part B Section 3 and Table 6), or may change with time; or situations in which the modeling methods used to derive Tier 1 guideline values are not valid or applicable.

Where modifications result in a requirement for land or water use restrictions or where administrative or physical controls are required to meet protection objectives, these are considered under "Exposure Control" as noted in Figures 3 and 4.

4.2 Eligible Exposure Pathway/Receptor and Parameter Modifications for Tier 2

4.2.1 Pathways and receptor exclusion

For some specific substances of concern, there are separate Tier 1 Guidelines that have been developed for subsoil and surface soil. For these substances, Tier 1 Guidelines may be applied to the subsoil provided the site meets the requirements as outlined in the companion Alberta Tier 1 document (see AENV, 2007a) for more detail on the availability and application of the subsoil guidelines).

Certain exposure pathways or pathway-receptor combinations may be excluded at Tier 2 if they are not operative at a given site and their exclusion does not lead to a requirement for land and/or water use restrictions. The following section deals with exceptions where pathways and receptors may be excluded. A number of exposure pathways are mandatory and are therefore ineligible for exclusion at Tier 2 regardless of whether they are operative. Where the pathway/receptor is not specifically documented in this guideline, it must always be considered mandatory.

Exposure pathways for potable groundwater, surface water supporting aquatic ecosystems and surface water used for wildlife watering may be excluded if not applicable. Details for these exclusions are provided in Part B Section 3. For all applications, potential for future use of a surface water body must be considered regardless of current use. Similarly, where an aquifer is defined as a Domestic Use

Aquifer or can be used for irrigation in agricultural land, the Tier 1 guideline for groundwater applies at any point in the aquifer, regardless of current water use. Suitability of an aquifer for domestic use is based on considerations of the properties of the aquifer and defined in Section 2.5 and Appendix E.

For agricultural land use, shallow groundwater may be intercepted by dugouts or surface water that may be used for irrigation or livestock watering. Therefore removal of these pathways is generally considered Exposure Control due to potential for future development. Exceptions may be available for contaminated soil or groundwater that is deeper than surficial excavations for these purposes. In this instance, demonstration that the aquifer is not suitable for irrigation or livestock watering or that there is an isolating unit between the base of the contaminant and the aquifer of concern can be used to rule out this pathway. These exceptions are considered under the Tier 2 site-specific risk assessment option.

4.2.2 Guideline Adjustment

The Tier 1 guidelines that are derived on the basis of fate and transport modeling may be modified where appropriate by the substitution of site-specific values for certain measurable and stable parameters (referred to as Tier 2 Guideline Adjustment). Tier 2 Guideline Adjustment is based on the use of clearly defined, chemical fate and transport models used to develop the Tier 1 guideline for the contaminant of concern. Therefore, parameter adjustment at this level is currently only available for the vapour inhalation and groundwater protection pathways. For more detail, see Part B of this document.

The use of site-specific parameters for Tier 2 Guideline Adjustment must be supported by adequate site data justifying the selection of the values used. Use of site-specific parameters must also be supported by measurements from the appropriate depth and locations that are representative of the requirements imposed by the chemical fate and transport model and must be shown to reasonably capture potential spatial and temporal variation of the parameter at the site. If variable, the parameter chosen for substitution in the model must be a conservative estimate based on the distribution in values observed for the site. Use of mean values do not generally lead to conservative estimates and are not acceptable model inputs.

The decision to undertake Tier 2 adjustments is a commitment to increase the "realism" or accuracy of the modeling. Therefore the commitment must also be made to ensure an increased certainty in the level of environmental protection offered by the Tier 2 evaluation. Where the effect of an adjustment in one or more parameters is a decrease in the calculated guideline value, the lower site-specific value must be used rather than the Tier 1 guidelines. Where measurements are highly variable or uncertain or where insufficient data is available to reliably predict the parameter, the Tier 2 option is not available. Parameters for which site-specific values may be used are discussed in detail in Part B.

4.3 Exposure Pathway or Point-of-Exposure Measurements

Exposure pathway or point-of-exposure measurements of contaminant concentrations, if substituted for predicted values in the fate and transport models used to derive the Tier 1 guideline values, may be used to increase the realism of the modeling and potentially allow relaxation of the Tier 1 value. Examples of such measurements include soil vapour concentrations, groundwater concentrations measured at points between the contaminant source and the identified receptor location, or direct ecological toxicity testing where standard protocols and references have been defined in other guidance supplied by Alberta Environment.

Due to the potential for large variability in measuring exposure pathway or point-of-exposure concentrations, this option is considered to be Tier 2 SSRA and is beyond the scope of this document. See Appendix D for some general guidance on this option.

4.4 Tier 2 Assessment and Evaluation

The implementation of the Tier 2 approach is illustrated schematically in Figure 3. The steps in the process are described briefly below and further details are provided in Part B and the Appendices.

4.4.1 Additional data collection

Upon entering Tier 2, the proponent will have undertaken an assessment that fulfils the requirements for Tier 1 and provides sufficient information to support the decision to proceed to Tier 2. If Tier 2 adjustments are limited to the exclusion of certain eligible pathways that are inoperative on a site-specific basis, additional site data are often required, but are generally restricted to demonstrating that a particular exposure pathway/receptor is not applicable to the site in question. For instance, exclusion of the drinking water requires demonstration that the aquifer does not fit the definition of a DUA or that there is a natural geologic barrier between the DUA and the impacted aquifer, but would not necessarily require other types of data collection for the site.

If Tier 2 involves the recalculation of Tier 1 guidelines based on site-specific parameters, sufficient data must be obtained to ensure the reliable determination of the applicable parameter values. The required data will depend on the governing exposure pathway that is to be modified.

The decision to undertake Tier 2 adjustments requires a commitment to increase the accuracy of the exposure and risk estimates. Therefore, site-specific data must include the measurement of <u>all</u> readily quantifiable parameters that are influential with respect to the governing pathway, particularly where one parameter tends to either correlate with or influence the value of another parameter in practice. Site-specific data may include: physical soil properties such as texture, organic carbon fraction, porosity and moisture content; hydrogeological conditions such as depth to groundwater, hydraulic conductivity and hydraulic gradient; depth to contamination; and distance to fixed receptors such as surface water bodies.

4.4.2 Recalculation of objectives based on site-specific parameters

Once site-specific parameters have been determined and the applicability of the Tier 2 approach for the subject site and governing exposure pathway(s) has been verified, Tier 2 soil and/or groundwater objectives are calculated using the Tier 1 modeling methods and the site-specific parameter values. Details of the calculation methods are provided in Part B and the Appendices.

4.5 Tier 2 Decision and Management

The Tier 2 decision process is illustrated in the lower part of Figure 3. Initially, the measured contaminant concentrations are compared with the adjusted Tier 2 objectives. If no exceedances are found at this point, and contaminant sources have been removed, the site can be considered to be in compliance with Tier 2 and no further action is required. Compliance with Tier 2 will lead to regulatory closure.

Where the modified Tier 2 guideline appear to be over-protective, the proponent has the option of moving to a more detailed Tier 2 SSRA option, or to Exposure Control. However, Tier 1 or the Tier 2 Guideline Adjustment will lead to less need for ongoing monitoring, less rigorous data requirements to support decision making and more certainty for regulatory closure.

Where soil and/or groundwater conditions exceed Tier 2 objectives, implementation of Tier 2 will involve the development of a remediation plan and the remediation of soil and groundwater to achieve the Tier 2 objective.

5. OVERVIEW OF TIER 2 SITE-SPECIFIC RISK ASSESSMENT OPTIONS

The main purpose of this section of the guidance is to provide a brief overview of the principles of site-specific risk assessment for the Tier 2 approach and discuss situations that would lead to the implementation of this option. A detailed guidance on how to conduct a Tier 2 site-specific risk assessment is beyond the scope of this guideline. Exposure Control is discussed further in Section 6.

Management involving more detailed site-specific risk assessment and the application of site-specific remediation objectives (i.e. Tier 2 SSRA) may be available under Tier 2 and therefore is available for regulatory closure. Where the management plan requires administrative or physical controls to assure that ecological and human receptors are protected, sites will not be available for regulatory closure until the final Tier 1 or Tier 2 risk-based objectives have been achieved and the need for controls is no longer required.

In all instances, site-specific remediation objectives will require use of procedures, protocols, and monitoring that are acceptable to Alberta Environment. Where there are no clear guidance documents that have been accepted by Alberta Environment, discussion with Alberta Environment will be necessary prior to acceptance of final Tier 2 SSRA remediation objectives.

5.1 Conditions Triggering Site-specific Risk Assessment

Site-specific risk assessment may be triggered by a number of conditions. These include situations in which Tier 1 and/or Tier 2 pathway and receptor exclusion and guideline adjustment approaches are either precluded by technical or policy factors or where site-specific risk assessment is clearly demonstrated to offer the same level of protection as the Tier 1 objectives.

Situations giving rise to Tier 2 SSRA include, but are not limited to:

- Physical site conditions that violate Tier 1 model assumptions, necessitating the use of alternate modeling procedures
- Land or water uses not covered by the generic land and water use categories, and which cannot be addressed at Tier 2 by the addition or unconditional exclusion of exposure pathways (including the presence of unique exposure conditions or more sensitive receptors)
- Adjustments to site-specific parameters that are not readily measured or verified, or that are not fixed or stable
- Development of site-specific objectives for direct exposure pathways (e.g. ecological soil contact)
- Adjustment of objectives and/or modeling on the basis of exposure pathway or point-of-exposure measurements of contaminant concentrations (e.g. developing soil or groundwater Tier 2 SSRA guidelines by monitoring soil vapour concentrations of a certain volatile organic compound)

5.2 Basis and Considerations for SSRA

5.2.1 Pathways and receptors

Tier 2 SSRA provides the opportunity to consider additional receptors and exposure pathways on a site-specific basis beyond those prescribed under the generic Tier 1 land and water use scenarios.

Receptors and exposure pathways may also be excluded using site-specific risk assessment. However, where the exclusion leads to a requirement for ongoing management or land and/or water restrictions, Tier 2 regulatory closure is not available. For example, excluding a child receptor from a commercial site leads to ongoing access restrictions that limit the use of that land.

5.2.2 Parameters

Development of site-specific remediation objectives may include parameters or models that are beyond the scope of this document. However, this approach will require some form of validation supported by additional site-specific data to demonstrate that the site condition meets the protection objectives. Where information collected can demonstrate with sufficient confidence that the protection goals required have been achieved, regulatory closure may be available. Alberta Environment should be consulted in these specific cases.

5.2.3 Human Health and Ecological Protection Endpoints

Human health and ecological protection endpoints must be maintained in keeping with Alberta Environment's requirement for the same level of human and ecological protection at all tiers of management. Modification of endpoints normally requires some form of on site restrictions or management options. These are typically considered Exposure Control and therefore are not eligible for regulatory closure.

The procedure under SSRA is generally different than that of other options described in Tier 1 or in this document. Usually, SSRA cannot be used to derive guidelines for protection endpoints of a critical receptor. Rather, the approach is to establish whether a fixed level of protection has been achieved for the receptor at risk given the current on-site conditions. For instance, soil vapour monitoring or direct ecological testing might be available to demonstrate that the human or ecological receptor is protected given the current conditions at the site, but may not be able to demonstrate the necessary protection for the range of possible uses under the current zoning.

5.2.4 Alternative Fate & Transport and Exposure Models

There may be cases where there is a requirement to employ chemical fate and transport or exposure models that are different from Tier 1 due to situations where Tier 1 generic guidelines may not apply. Here, it may be possible to develop a site-specific remediation guideline based on alternative modeling protocols. However, in the majority of these instances, there will be a need for additional monitoring and data collection to verify model assumptions. Since the data collection exercise is generally tied to a specific site and a specific period of time, this approach generally restricts application to an

assessment of risk for the site rather than development of a criterion on which the assessment can checked against.

5.3 Implementation of Site-specific Remediation Objectives

5.3.1 Data requirements

The information required to conduct an SSRA must include sufficient site and contaminant characterization, data pertinent to fate and transport modeling, receptor characteristics, toxicity information and other information needed to permit the site-specific quantification of risk and establishment of remediation objectives.

The SSRA involves requirements for information that may vary both spatially and temporally. Information must be comprehensive enough to fully demonstrate the spatial and temporal variations that may be involved. Use of the SSRA approach will require monitoring, often coupled with more detailed modeling procedures, for a sufficient period of time to demonstrate that protection objectives are met and model predictions will continue to correlate with residual concentrations in the future. The variability of parameters leads to some uncertainty in predictions. Therefore as part of the site closure, this approach will require some ongoing monitoring often coupled with more detailed modeling procedures to demonstrate how measurements will continue to correlate with contaminant concentration given potential for temporal and spatial variability at the site.

The data collection required for SSRA will depend on the critical exposure pathways and receptors and the availability and applicability of relevant data from other sources for aspects such as toxicity. Provision of a detailed protocol for data collection is beyond the scope of this document but the proponent should be guided by the need to ascertain with a reasonable level of confidence the following:

- nature, degree and extent of contamination
- physical, chemical and hydrogeological characteristics of site soil and groundwater
- building characteristics, if applicable
- human and ecological receptors and their associated exposure factors. In both instances the choice of receptors must consider the need for preservation of the entire range of human or ecological function within the given land use category. It may therefore be necessary to develop a complete inventory of potential human and ecological receptors that may be important to a site prior to determination of the critical sensitive receptors.
- receptor-specific toxicity information which, in the case of ecological receptors, may require toxicity testing and, at more detailed levels of ecological risk assessment, tissue sampling and analysis

SSRA will typically require some form of monitoring to verify predictions. Therefore, data collection should also provide sufficient information to serve as a baseline for long term monitoring of relevant parameters.

5.3.2 Principles of site-specific risk assessment

The user is referred elsewhere for detailed guidance on human health and ecological risk assessment (e.g. US EPA, 1989, 1997; Health Canada, 2004b, 2004c, 2006; CCME, 1996b, 2006a). The basic steps involved in risk assessment are summarized below. References are provided as guides only. Where guidance is not available from Alberta Environment, it is up to the user to verify that methods used will be acceptable to Alberta Environment prior to proceeding.

Problem formulation

Problem formulation includes identifying the contaminants of concern, the human and ecological receptors and the potential those receptors can become exposed to the contaminants. Complete exposure pathways require a mechanism of chemical release to the transport medium, a transport pathway from the contaminant source to the receptor, and a route of intake at the receptor location. Incomplete pathways may be eliminated on a site-specific basis at this stage, and the complete or potentially complete pathways are incorporated into a conceptual model of the site, which serves as the basis for the subsequent steps of the assessment.

Where regulatory closure is desired, the user will need to assess *potentially* available pathways and receptors that were used to develop the Tier 1 guidelines for the applicable land use category. Where incomplete exposure pathways exist due to barriers, caps or land use restrictions that limit receptor exposure, etc., these are considered forms of Exposure Control and are not eligible under the Tier 2 remediation guideline closure option. Exceptions are provided for natural geologic barriers under the DUA exclusion option (Appendix E). Additionally, the absence of certain structures, receptors, or uses at a site where there is potential for their presence cannot be used to support a decision for eliminating exposure pathways under the Tier 2 option. To do so is considered a form of Exposure Control. For Tier 2, all potential uses and receptors must be considered to be present at the site regardless of the current site inventory.

Toxicity assessment/hazard assessment

The toxicity assessment or hazard assessment comprises the establishment of either a dose-response relationship or a toxicological or effects-based endpoint value for each contaminant of concern. Toxicity reference values and reference concentrations used to develop the Alberta Tier 1 guidelines are included in the companion document (AENV, 2007a). In keeping with Alberta Environment's requirement for the same level of human and ecological protection at all tiers of contaminated site management, these reference values must be maintained.

Toxicity reference values used to develop the Alberta Tier 1 guidelines are given priority for human health risk assessments. If the compound is not referenced, the following sources may be of some assistance, in order of priority:

- Health Canada (2004c);
- CCME;

- The United States Environmental Protection Agency (IRIS database); and,
- The United States Oak Ridge National Laboratory toxicological database.

Where published literature differs, choice of toxicity reference values are subject to review and acceptance by Alberta Environment.

In the case of ecological risk assessment, due to the wide variety of potential receptors, published effects-based data are usually only available for limited test species. Procedures for selecting and utilizing published data to develop threshold effects doses or guidelines for various receptors are documented by CCME (2006a). For site-specific and receptor-specific ecological risk assessment, it may be necessary to supplement such values through additional literature review and toxicity testing.

In general, ecological toxicity values that have been developed or adopted for the Alberta Tier 1 guidelines are the first source of information for toxicity reference values applied to ecological risk assessment. There is a limited ability to redevelop toxicity reference values for site-specific conditions where there are clear receptors of concern and effects may be based on site-specific conditions, or through direct ecological toxicity testing. This option is based on available protocols as accepted and defined for the substances of concern by Alberta Environment. A full description of protocols for site-specific ecological risk assessment is beyond the scope of this document and the user should consult Alberta Environment if direct ecological toxicity testing is proposed.

Where no toxicity reference values exist for a given ecological receptor, the user may be required to develop a toxicity reference value as per protocols outlined in CCME (2006a) and based on literature or direct toxicity testing procedures.

Exposure assessment

Exposure assessment defines the relationship between the contaminant concentration at the source and the exposure or intake at the receptor location, considering both the fate and transport of the contaminant and the behavioural characteristics of the receptor. For direct pathways, exposure assessment involves determining the intake as a direct function of the source concentration to which the receptor is exposed. For indirect pathways the exposure assessment normally involves modeling of the fate and transport mechanisms, including cross-media partitioning of the substance into soil, air or water.

Point-of-exposure measurements may be used to reduce the level of uncertainty in the modeling. However, this approach may require ongoing monitoring and/or more detailed modeling procedures to demonstrate how measurements will continue to correlate with the contaminant concentration given potential for temporal and spatial variability at the site. Therefore, the majority of site-specific risk assessments will require an ongoing monitoring plan, until a stable condition can be demonstrated to support a Tier 2 remediation objective.

The models and algorithms recommended for use in Canada for the principal exposure pathways are described in CCME (2006a) and Health Canada (2004b). Other methods may be found in ASTM (1995, 1998). The methods used in the derivation of the Alberta

Tier 1 guidelines are described in the companion Tier 1 document and are summarized in Appendix A. Data on receptor characteristics for the Canadian population have been compiled by Richardson (1997) and are summarized in CCME (2006a) and Health Canada (2004b).

Risk characterization

Risk characterization consists of combining the estimated exposure intakes of the contaminants of concern, with the established toxicity data to obtain an estimate of risk. For threshold compounds or non-carcinogens, human health risk is expressed in terms of hazard index; risk for non-threshold compounds or carcinogens are presented as a lifetime incremental cancer risk. Ecological risk is commonly expressed as an exposure ratio, analogous to a hazard index. If assumptions in the risk assessment are sufficiently conservative, then hazard indices or exposure ratios of less than unity, based on all sources of exposure, signify negligible potential for adverse effect.

As part of the risk characterization process, the established relationships between source concentration and risk are used to back-calculate source concentrations corresponding to target risk levels. In this way site-specific risk-based remediation objectives are established for each pathway and receptor. The critical exposure pathway is identified on the basis of the lowest applicable objective, which then becomes the governing objective for the site.

A SSRA will generally be carried out using deterministic methods and will be based on conservative assumptions about the characteristics of receptors and critical pathways. Deterministic methods have been used in the development of the Tier 1 values, and are implicit in the Tier 2 adjustment procedures.

The use of probabilistic methods is becoming an increasingly common practice in Canada for SSRA, particularly for human health. Probabilistic methods provide a consistent and defensible method of accounting for uncertainty and natural variability in key assumptions such as site conditions and receptor characteristics. The use of probabilistic methods may be subject to a reduced level of transparency and reproducibility. Therefore, although probabilistic risk assessment provides insight that can facilitate risk management decision from the standpoint of level of protection or conservatism, the approach will not support an application for regulatory closure under Tier 2. Nevertheless, it is recognized that probabilistic models may allow for some guidance in determining procedures for Exposure Control where site management decisions need to be developed.

5.4 Identification of Conditions/Restrictions Associated with Site-Specific Risk Assessment

As noted previously, SSRA may permit regulatory closure, provided the site-specific data are adequate, the parameters utilized in the risk assessment are fixed and stable, and the exposure conditions assumed are at least as protective as the default assumptions used at Tier 1 and Tier 2. This will, however, generally result in some need for ongoing monitoring and/or validation of assumptions. Therefore, SSRA will require a monitoring

plan as part of the risk assessment until stable endpoints can be demonstrated. Generally, this form of risk assessment cannot be used to develop risk-based guidelines but may be applied to establish the potential for risk associated with the presence of a residual contaminant under the set of site-specific conditions at a given site.

Regulatory closure is not available if the site-specific conditions require ongoing Exposure Control to limit risk to critical receptors or ongoing monitoring to validate those risks. Therefore if land or water use restrictions are implicit or explicit in the exposure assumptions and/or if residual contaminant concentrations are associated with unacceptable levels of risk to receptors the site will require Exposure Control (discussed further in Section 6).

6. EXPOSURE CONTROL

Exposure Control includes site management measures designed and implemented to ensure that exposures do not result in human and ecological risks in excess of levels considered acceptable. The role of exposure control in the control of risk at contaminated sites is captured in Figures 1 to 3. Figure 4 provides more information on how exposure control is implemented.

Exposure Control is required when contamination exceeds Tier 1 or Tier 2 remediation guidelines where measures to preserve the site conditions or exposure assumptions are required to obtain acceptable risk levels, or otherwise to limit exposure to acceptable levels. Conditions that give rise to exposure control include but are not limited to:

- Adjustments to site-specific parameters or exposure pathways/receptors that require management or control measures
- Adjustments to site-specific parameters or exclusion of pathways that result in conditions or restrictions on land and/or water use
- Practical or economic limitations to feasibility of remediating to Tier 1 or Tier 2 objectives
- Decision to implement long-term risk management (e.g. in association with long-term remediation, or at an operating facility)

Exposure Control may include long-term risk management options that are designed to eventually meet a Tier 1 or Tier 2 objective. For instance, Exposure Control may involve some form of natural attenuation, biodegradation, source depletion and other transformation mechanisms. Although these mechanisms may be successful in achieving a Tier 1 or Tier 2 remediation objective, the exposure control option is necessary until the closure condition is met.

Exposure Control options will require monitoring to verify predictions and the efficacy of the control. Therefore data collection should also provide sufficient information to serve as a baseline for long term monitoring of relevant parameters. For options that involve natural processes such as natural attenuation, biodegradation, source depletion or other transformation mechanisms, the monitoring program must include data collection to support evidence of these processes.

6.1 Role of Exposure Control

In the context of Alberta's risk management framework for contaminated sites, Exposure Control is not required if sites are remediated to Tier 1 or Tier 2 remediation guidelines or if acceptable risk as defined through a site-specific risk assessment acceptable to Alberta Environment has been obtained. Remediation to Tier 1 or Tier 2 objectives is eligible for regulatory closure.

Examples of sites that would be considered to fall under the Exposure Control option are as follows:

1. A remediation plan requires a period of time to achieve the derived Tier 1 or Tier 2 risk-based remediation objective. Exposure Control is required to ensure that short-term contaminant levels in excess of guidelines do not give rise to unacceptable risks. For instance, remediation plans that involve some form of natural attenuation, biodegradation, source depletion or other transformation mechanisms may be used to eventually achieve an acceptable risk level across the site but may also require interim Exposure Control to manage the immediate risk to receptors.
2. There are modifications to exposure assumptions or exclusion of exposure pathways that are not supported by Tier 2 policy. This type of modification is likely associated with administrative or physical requirements to manage exposure for the given pathway and therefore, will fall under the Exposure Control option. For example, exclusion of the human direct soil contact pathway based on depth to contamination requires measures to ensure the soil is not disturbed or placed in an accessible location.
3. Site-specific parameters or modifications are applied to reflect current site conditions or land uses, but have a reasonable potential to change with time. Although a risk assessment may demonstrate that the level of risk associated with the site is acceptable at the time of analysis, the need to ensure that management of the site stays consistent with assumptions built into the risk assessment will require the use of the Exposure Control option. For example, use of site-specific building parameters to control risks from the vapour inhalation pathway requires ongoing site management to ensure that these parameters remain in operation.

In these situations, the measures required to ensure that the conditions on which the risk assessment or site-specific objectives are based must be maintained over time and therefore will not be considered for regulatory closure.

Where Exposure Control is employed, it is the responsibility of the proponent to ensure long-term viability and care and control of the risk management plan. This also requires the proponent to ensure the Exposure Control is maintained until risk levels are acceptable for all potential land uses associated with the site. Acceptance of the risk management plan by affected property owners is also necessary under this approach.

A site management approach that relies primarily on Exposure Control must address the fundamental requirements of Alberta Environment's policy for the management of risks at contaminated sites as outlined in Section 2.5.7 including source control, mitigation of offsite contamination, odours, safety and nuisance conditions, long term maintenance of administrative or physical exposure controls used at the site, environmental monitoring for the duration of the period where controls are needed, and the requirement that EPEA not be contravened.

6.2 Approaches to Exposure Control

Exposure Control is divided into two main categories: administrative or institutional controls and engineered or physical controls. Environmental monitoring is normally

applied to assess the efficacy of either category of risk management, to ensure that receptors remain protected.

6.2.1 Administrative or institutional controls

Administrative or institutional controls are measures applied through operational policies that ensure exposure conditions continue to conform to the assumptions used in the risk assessment or in the derivation of the site-specific objectives. Examples of Exposure Control by administrative or institutional controls include:

- Security programs to restrict access to a contaminated site
- Establishing discretionary land uses through consultation with zoning authorities and land use bylaws
- Groundwater use restrictions
- Worker health and safety programs
- Contingency soil management plans in the event of future excavation or other disturbance
- Building placement restrictions on a property
- Recommendations for design, installation and maintenance of utility service lines
- Restrictive covenants and caveats on land titles aimed at development restrictions
- Contracts providing for obligations of a party to maintain a management plan
- Programs to prevent activities that place humans or the environment at risk

6.2.2 Engineered or physical controls

Engineered or physical controls are measures that involve the use of physical or chemical barriers to prevent or reduce exposure to contaminants at or near a site. Examples of risk management by engineered or physical controls include:

- Soil cover to prevent direct exposure to contamination
- Constructed impermeable barriers and liners to prevent contaminant migration
- Hydraulic controls to limit or alter groundwater flow in order to reduce dissolved contaminant transport
- Sub-floor vapour control systems or barriers to prevent ingress of volatile organic compounds into buildings
- Fencing around a property to restrict access
- Physical or chemical modification or fixation of contaminants to reduce bioavailability or mobility
- Point-of-exposure or point-of-use controls such as water treatment or air filtration

6.2.3 Monitoring

Monitoring, in this context, includes the monitoring, sampling and/or analysis of contaminant concentrations in an environmental medium (soil, soil vapour, groundwater, surface water, air) at a contaminant source, a point of exposure or at an intermediate location. Monitoring is conducted as part of a risk management plan for a number of reasons, including:

- Determining contaminant concentrations in potential exposure media
- Ongoing confirmation of site or subsurface conditions, particularly those that may be expected to change with time
- Field validation of fate and exposure models used in site-specific risk assessment
- Monitoring the progress of long term remediation or natural attenuation processes
- Verification that generic guidelines are being met at points of compliance
- Triggering of further risk management actions as needed

Monitoring is an essential component of any Exposure Control scenario. Monitoring plans are therefore required for any scenario involving Exposure Control. Commitment to a monitoring plan and continuance of the monitoring plan until such a time as contaminant concentrations are at acceptable levels is required for any Exposure Control scenario.

6.3 Circumstances that Preclude Exposure Control

While Exposure Control would be required in most situations where contaminant concentrations exceed Tier 1 or Tier 2 objectives, including the implementation of long-term remediation measures designed to meet such levels, certain circumstances preclude the selection of risk management as a primary strategy for the management of contaminated sites.

Sites that have prescribed outcomes by a regulatory order under EPEA cannot be managed using Exposure Control, unless the order specifically allows this option.

Sites where the risks cannot be managed using Exposure Control options would not be eligible for Exposure Control (see Figure 4). If risks cannot be managed at the site, it is up to the proponent to ensure that the site is remediated to the appropriate risk-based objectives based on either the Tier 1 or Tier 2 approach.

Contamination on public or third party land may not be managed in any way that leads to land or water use restrictions, unless agreed to by the affected landowner. Furthermore, management objectives must aim to achieve drinking water objectives in the Domestic Use Aquifer, rather than long-term exposure control. Exposure Control may, however, be required in conjunction with ongoing remediation if the Tier 1 or Tier 2 remediation guidelines cannot be reasonably achieved in the short term. In these instances, it is also necessary to ensure that affected third parties will accept the plan.

6.4 Requirements for Exposure Control

Exposure control always requires development of a plan that will detail how the proposed site management strategy will be implemented. Where Exposure Control is included in the proposed site management strategy, a number of requirements listed below must be met:

Appropriateness of risk management to site conditions

- Contamination in soil and groundwater must be completely delineated. For volatile contaminants where the risks are potentially associated with soil vapour concentrations, soil vapour must also be delineated for the site.
- All sources must be managed according to the principles outlined in Section 2.3.1.
- Where there is non-aqueous phase liquid (NAPL), the NAPL must be fully remediated, removed, or measures must be in place for complete control or management of the NAPL as defined in section 2.3.1.
- Where the efficacy of the exposure control option (e.g. engineered barrier) has the potential to be negatively affected by contamination that may be present, alternate management options must be employed or steps taken to mitigate the impact.
- The contamination must not cause adverse effect under the Exposure Control option. Adverse effect is defined in the *Environmental Protection and Enhancement Act* as impairment of or damage to the environment, human health or safety or property.
- Where monitoring indicates that health or ecological protection objectives in the Exposure Control plan are not being met, alternate management options must be employed. For instance, where monitoring at points of compliance indicates that the condition is worsening with time, there is a need to move to other remediation or management options.

Approval and commitment of stakeholders

- All land or water use restrictions and/or administrative or institutional controls must be clearly defined and communicated to affected stakeholders. This must include clearly defined points of compliance where the contaminant concentration is expected to meet the required Tier 1 or Tier 2 objectives.
- The Exposure Control option, including any required land use restrictions, administrative controls, institutional controls and access requirements must be agreed to by affected third parties.
- The owner or responsible party must commit to maintenance of the Exposure Control scenario indefinitely, or until compliance with governing objectives has been demonstrated.
- The owner or responsible party must agree to ongoing monitoring and develop a monitoring plan that is acceptable to Alberta Environment.

Technical adequacy of Exposure Control plan

- The Exposure Control plan must: protect any potential for adverse effect to human health and the environment; monitor on-site and off-site conditions; prevent worsening of off-site conditions; manage contamination if disturbed by future activities (e.g. excavation); and notify future affected parties of site conditions
- The plan must include contingency measures to respond to adverse changes in conditions. For example, if contaminant concentrations in a plume are not stable or decreasing with time, alternate risk management measures are required.
- The plan must include a monitoring plan. The scope and frequency of monitoring must be adequate to assess effectiveness of the plan, including both engineered and administrative controls and identify the need for contingency measures.

PART B: USER GUIDANCE FOR TIER 2 MANAGEMENT UNDER THE PATHWAY EXCLUSION AND GUIDELINE ADJUSTMENT OPTIONS

1. INTRODUCTION

Part A of this guideline provides an overview of the framework for managing contaminated sites in Alberta and the stages and decision points for proceeding through the tiered system. Part B provides prescriptive guidance for implementing Tier 2 Guideline Adjustment, including the data requirements and modeling procedures for developing Tier 2 Guideline Adjustment remediation objectives. Detailed guidance for Tier 2 Site-Specific Risk Assessment is beyond the scope of this section.

The relationship of Tier 2 to other options in the management framework is illustrated in Figure 1 and the Tier 2 process is shown schematically in the flow chart presented in Figure 3.

2. CONDITIONS TRIGGERING TIER 2

As described in Part A of this guidance, the decision to proceed with Tier 2 management of a contaminated site is based on a number of possible triggers related to site-specific conditions.

2.1 Conditions Precluding Use of Tier 1 Guidelines

The use of Tier 1 guidelines may be precluded by site-specific factors that invalidate the modeling used in the derivation of the generic guidelines or result in a higher degree of exposure than that considered in the generic exposure scenario. These exceptions are explained in more detail in the companion Tier 1 document (AENV, 2007a). They include:

- Source of volatile contaminants present within 30 cm of a building foundation
- Unique building features, including earthen floors or unusually low air exchange rates
- Sensitive receptors that are present but not accounted for in the generic Tier 1 land use description
- Groundwater flow to stagnant water bodies
- Soil or groundwater contamination present within 10 m of a surface water body
- Very coarse textured materials enhancing groundwater or vapor transport
- Contamination in fractured bedrock
- Contaminant source length parallel to groundwater flow greater than 10 meters
- Organic soils

If any of these conditions exist at the site, a Tier 2 approach must be taken to determine whether the level of protection afforded by the Tier 1 guideline is protective or whether

the Tier 1 guidelines must be lowered to account for the risk associated with the site-specific conditions.

Secondly, the assumptions used to derive the generic guidelines may be conservative relative to site-specific conditions, such that less stringent guidelines could be developed based on site-specific assumptions without reducing the level of human health and environmental protection.

Specific conditions under which the Tier 1 values are not valid are listed in Table 1. Situations where site conditions may give rise to higher degrees of exposure are also summarized in Table 1. Further guidance may be obtained by comparing site-specific parameters with the default Tier 1 assumptions presented in Appendix A.

If the above situations can be accounted for by the site-specific adjustment of relevant parameters, or inclusion of more sensitive receptors or exposure scenarios, the approach outlined here can be used. However, if alternative modeling approaches are required, this would necessitate proceeding to Tier 2 SSRA.

2.2 Conditions for Tier 2 Guideline Adjustment

If the default assumptions used in the derivation of the governing Tier 1 values are conservative relative to actual site-specific conditions, the replacement of default assumptions with site-specific data for certain influential parameters may permit the development and implementation of Tier 2 objectives. There may also be some opportunity to use exposure pathway or point-of-exposure measurements to reduce model uncertainty, as dealt with under the site-specific risk assessment category.

Tier 2 adjustments are only likely to be of benefit when applied to parameters that affect the governing exposure pathway. The soil and groundwater remediation guidelines presented in Appendices A and B in the companion Tier 1 guideline document (AENV, 2007a) can be used to determine the governing pathway for a given chemical, land/water use and soil type. Table B.1 in Appendix B provides some qualitative information on the parameters that are potentially influential on the guidelines for the various governing pathways. This table is provided as a guide only. The influence of a given parameter may be highly chemical-specific and highly dependent on the values of other parameters. Therefore, more detailed procedures as outlined in this section of the guidance and Appendix C would be required to assess the magnitude and direction of any potential change. The table may be used to assist in a preliminary screening of the opportunity for Tier 2 management. If the governing exposure pathway is one for which no simple parameter adjustments to a model are available, there may be opportunity to refine model predictions through Tier 2 SSRA.

Where a site-specific condition is expected to result in exposure risks greater than those used in conservative Tier 1 assumptions, or where the critical receptor may be at greater risk than in the generic condition, site-specific risk assessment to determine risk to the critical receptor must always be undertaken. Where this leads to assurance that receptors are still protected at the generic level, the generic guidelines may still be used.

Where Tier 2 Guideline Adjustment or Site Specific Risk Assessment is not available for the critical exposure pathway, then the Tier 1 remediation guidelines must be adopted. Exposure control options may still be available subject to other conditions described in Section 6 of Part A.

If the user chooses to implement a Tier 2 approach or if there is a requirement to proceed to Tier 2 due to site-specific conditions, it is necessary to determine whether such adjustments would constitute a Guideline Adjustment or a SSRA. Tier 2 Guideline Adjustments made here are limited to three principal criteria:

1. They are limited to factors influencing exposure that can be measured and verified.

   Guideline Adjustments must relate to stable site characteristics that affect contaminant fate and transport and human and ecological exposure. Examples include physical soil properties, distances to receptor locations (where these can be considered fixed) and, in some cases, form and composition of the contaminant. These characteristics must be readily quantifiable, and their effects on the numerical objectives must be capable of determination without departing from the scientific principles used in the derivation of the Tier 1 standards.

2. They must support clear and consistent land and water use decision making

   Guideline Adjustments cannot compromise the generality of the defined land and water uses. If they lead to land or water use restrictions, these must be clearly identified. Adjustments leading to restrictions are not allowed under the Tier 2 approach.

3. They must be simple and straightforward in their determination and application

   Part of the philosophy of a multi-tiered system is that each successive tier requires a greater level of investigative effort and a potentially greater degree of regulatory intervention. It is expected that a majority of sites will be managed using the Tier 1 and Tier 2 Guideline Adjustment approach, and progressively fewer at the higher tiers. The goal of the Alberta framework is that both Tier 1 and Tier 2 can be implemented consistently.

Parameters and assumptions that influence the Tier 1 (and hence Tier 2) values and meet the above requirements are listed in Table C-1 of Appendix C and are referred to as primary Tier 2 adjustable parameters.

In addition to the primary parameters, other parameters influence the remediation objectives but do not comply with one or more of the criteria listed above. These are referred to as secondary adjustable parameters. Although some of these may be accommodated in the Tier 2 approach, any that necessitate a land or water use restriction are not presently allowed at Tier 2. At this time, only mixing zone thickness and aquifer thickness, where appropriately supported are allowed in the secondary parameters. There are some specialized cases where horizontal offsets may also be allowed, but these are restricted to;

1. Zoning cases where the contaminant contained on a particular zoning (e.g. commercial, industrial) is being assessed for compliance on a neighbouring, more restrictive land use zone (e.g. residential) or;

2. Cases where the physical structures present on the site are more sensitive than assumed under the Tier 1 guideline development. For instance, where building parameters are more sensitive due poor air exchange rates or presence of an earthen floor basement or where bored wells are present in an aquifer that would not normally be considered a domestic use aquifer (see Appendix E), horizontal offsets to the structure of concern may be employed.

In all other instances, the use of a horizontal offset distance would typically lead to development restrictions that would not be available at Tier 2.

Certain exposure pathway or point-of-exposure measurements of contaminant concentrations, if substituted for predicted values in the fate and transport models used to determine the Tier 1 guidelines, may be used as a basis for modifying Tier 1 guidelines. The incorporation of exposure pathway or point-of-exposure measurements will be affected by sampling methods and locations, and will require more thorough verification as well as long-term monitoring to verify predictions. Concentrations measured at such locations may be a function of time; if measured values are less than predicted values, evidence must be obtained that the values are not likely to increase with time. This option is only available for Tier 2 SSRA or Exposure Control. Alberta Environment should be consulted on sites taking the SSRA or Exposure Control approach.

Based on the foregoing discussion, the proponent will be able to conclude whether the site-specific factors identified are permissible for Tier 2 Guideline Adjustment or whether a more detailed SSRA is warranted.

2.3 Conditions Precluding Implementation

Although a number of site-specific factors may mitigate exposure to human and ecological receptors, not all can be considered in the changes to model derivation. The preceding section identified some general criteria for assessing the potential for simple model manipulations. Based on these and other considerations, certain site-specific conditions would preclude the implementation of Tier 2 at a given site. In particular, any condition requiring land or water use restrictions would not be considered for Tier 2 modification. Conditions precluding the use of specific model changes, or which cannot be directly incorporated into the models described here, include the following:

- Modified receptor characteristics and exposure frequencies/durations, except where these address more sensitive receptors or greater degrees of exposure than those associated with the Tier 1 land or water use category
- Modified site-specific parameters or assumptions that require administrative or institutional controls in order to remain valid

- Exclusion of exposure pathways that may become operative in future under a particular land use category, or that requires management to ensure they remain inoperative. Where potential exists for development where a receptor may become present in the future or where an exposure pathway may become developed in the future, that must be considered in the development of the guidelines regardless of current land use.
- Modifications based on point-of-exposure or exposure pathway measurements. Modifications may be allowed at the Tier 2 SSRA level with the appropriate supporting information, but is not considered Tier 2 Guideline Adjustment. Alberta Environment should be consulted for Tier 2 modifications based on exposure pathway or point-of-exposure measurements.
- Modifications or exclusions that lead to any land or water use restriction.
- Site-specific properties that are not accounted for in the generic models, as described in Appendix C, section C.7.

3. ELIGIBLE MODIFICATIONS FOR TIER 2 GUIDELINE ADJUSTMENT

3.1 Introduction

When site conditions warrant, Tier 2 Guideline Adjustment is available for exposure pathways and receptors where Tier 1 guidelines were based on clearly defined chemical fate and transport models. The exposure pathways for which this option is presently available at Tier 2 are:

- Indoor vapour inhalation, based on the modeling of migration and intrusion of volatile substances in soil vapour into the indoor air of occupied buildings, and
- Protection of groundwater for
  - aquatic life
  - livestock watering
  - irrigation water
  - wildlife watering, and
  - potable water use

These exposure pathways employ modeling of contaminant leaching, mixing, dilution and, in the case of aquatic life or wildlife watering, lateral advective-dispersive transport in groundwater.

3.2 Exposure Pathways and Receptors

Tier 1 remediation guidelines have been developed for soil and groundwater, for a number of pathways under which a receptor could potentially become exposed. Under Tier 1 management, each exposure pathway is considered to be operative, and the associated Tier 1 guideline value is based on the default assumptions and parameters that represent generic exposure scenarios associated with the respective land and water use definitions. The exposure pathways and receptors considered under each land use are presented in Table 2; the general chemical properties for which the defined human health and ecological exposure pathways apply are shown in Tables 3 and 4.

At Tier 2, certain exposure pathways may be considered to be inoperative, or assumptions and parameters that govern exposure may be adjusted based on site-specific information. The eligibility for exclusion of a pathway or adjustment of a guideline value at Tier 2 is a function of the pathway, and is dictated by the considerations discussed in Section 2 above. Each of the exposure pathways or pathway-receptor combinations is discussed below with respect to eligibility for development of a Tier 2 remediation guideline through pathway exclusion or pathway modification in a chemical fate and transport model. Table 5 summarizes allowable exclusions and modifications.

<u>Direct human contact with soil</u>

Direct human contact with soil includes soil ingestion, dermal contact and inhalation of soil particulate. The degree of exposure through direct contact is primarily related to

characteristics of the receptor, therefore, site-specific factors are not readily accounted for in determining the soil guideline value. Direct soil contact is considered operative for all Tier 2 scenarios. Although direct human contact with soil may be avoided through exposure control, for example, where the soil is paved or capped and therefore inaccessible, or where contamination is present at depth, these require ongoing management measures to maintain the condition.

Direct human contact with soil is not available for site-specific exclusion or modification at Tier 2.

Human vapour inhalation

Inhalation of volatile contaminant vapours migrating into buildings applies in the case of volatile contaminants in situations where a building is or may be present. Since buildings may be present under all land use categories except natural areas, the vapour inhalation pathway cannot be excluded without imposing a land use restriction. Modification of the guideline values based on site-specific building location or configuration also leads to a land use restriction and/or management requirements. The Tier 1 remediation guideline values are derived from the modeling of vapour migration and intrusion, on the basis of a number of site-related parameters. Certain parameters are considered to be fixed and stable (see Section 3.3 below) and can therefore be adjusted on a site-specific basis without the need for restrictions or management measures.

Human vapour inhalation is considered to be operative in all cases at Tier 2, except in natural areas, but guideline values may be modified at the Tier 2 Guideline Adjustment level by substitution of certain site-specific parameters. Site-specific risk assessment of the vapour pathway may be possible but must consider the potential for building development anywhere on the site.

Ingestion of produce, meat and milk

Ingestion of produce, meat and milk applies for all substances, but becomes particularly critical for substances that bioaccumulate, under agricultural and residential/parkland land uses. More specific guidance on assessment of substances that may bioaccumulate or biomagnify may be found in CCME (2006a).

The guideline values are based primarily on receptor characteristics and bioavailability, and therefore cannot be modified at Tier 2. It may be possible to exclude the pathway under very specific residential/parkland conditions where zoning and/or development patterns preclude raising backyard produce, for example in some multi-family residential settings. In this case, it must be demonstrated that zoning is fixed to this land use.

Ingestion of produce, meat and milk is not eligible for Tier 2 Guideline Adjustment. It is considered to be operative under all agricultural and residential land use but may be excluded in a very narrow range of residential/parkland settings where backyard produce is excluded due to land use zoning and the pathway does not have potential to become a controlling pathway.

Protection of potable groundwater

Protection of potable groundwater is applicable in all cases where groundwater is, or has the potential to be used as drinking water. A Domestic Use Aquifer (DUA) is defined in Section 2.5 of Part A with specific details in Appendix E. This pathway may be excluded at Tier 2 where no DUA is present, or where a DUA exists but an adequate natural geologic barrier is present between the zone of contamination and the DUA. For more information, see Section 2.5 of Part A and Appendix E. Site-specific stratigraphic information and hydraulic conductivity measurements are required to demonstrate the presence of this isolation barrier.

The derivation of soil guidelines for the protection of potable groundwater is based on a leaching, mixing and dilution model that considers certain soil and hydrogeological parameters. Certain parameters are considered to be fixed and stable (see Section 3.3 below) and can therefore be adjusted on a site-specific basis without the need for restrictions or management measures. Tier 2 remediation objectives require drinking water objectives to be met everywhere within the DUA.

Distance to the groundwater user cannot normally be adjusted at Tier 2, since this would imply a restriction on groundwater use within the defined aquifer zone. An exception to this case exists when large diameter ("bored") wells are completed in geologic units that do not meet the hydraulic conductivity or yield criteria defining a DUA. In this case, the water well can be considered a receptor location and dealt with on a site-specific basis. The goal in this case is to ensure compliance with drinking water guidelines prior to the contaminant reaching the zone of influence of the large diameter well. Consultation with Alberta Environment is necessary for site-specific approaches in the presence of large diameter bored wells.

The groundwater ingestion pathway may be excluded at Tier 2 where no DUA is present, or where an adequate isolating layer exists between the DUA and zone of contamination. Where the pathway is operative, Tier 2 Guideline Adjustment may be undertaken by substitution of certain site-specific parameters. Site-specific risk assessment may be possible for the groundwater pathway, but must protect drinking water quality at all points within the DUA.

Soil contact (plants and invertebrates)

Soil contact for plants and invertebrates is considered under all land use categories. Exclusion of this pathway requires ongoing exposure control and therefore is not available at Tier 2. In some instances, there are subsoil guidelines available under the Tier 1 approach that may be based on different ecological considerations. These are noted for salinity and hydrocarbons in the companion Tier 1 document (AENV, 2007a).

Site-specific factors are not readily accounted for in determining the soil guideline value, with the possible exception of soil type. Therefore, any modification of the guideline value would necessitate site-specific toxicity testing and be considered under SSRA. At present, direct ecological toxicity testing for SSRA is restricted to a few specific compounds (e.g. petroleum hydrocarbons, benzene, toluene, ethylbenzene, xylenes)

where toxicity testing protocols are clearly defined and can be replicated in site-specific instances. Most ecological guidelines are either based on limited data sets that are not readily subject to site-specific verification (e.g. PAH guidelines) or more comprehensive data sets that are beyond the scope of most studies (e.g. salt guidelines) and therefore are not available for site-specific verification. Alberta Environment should be consulted prior to site-specific modifications of this pathway.

The soil contact pathway for plants and invertebrates is considered operative in all cases at Tier 2, and is not eligible for site-specific exclusion or Tier 2 Guideline Adjustment except for petroleum hydrocarbons where soil management guidelines exist below 3 m. Tier 2 SSRA by direct ecological toxicity testing may be permissible but is presently restricted to a limited range of contaminants.

Soil and food ingestion by livestock and wildlife

Soil and food ingestion by livestock is considered to be an operative pathway under agricultural land use; soil and food ingestion by wildlife is operative under the natural area land use. Livestock must also be included as a receptor at natural area sites where grazing leases are in effect. Soil guidelines for soil and food ingestion by livestock are not amenable to modification based on site-specific factors. Where this exposure has the potential to be a controlling pathway, particularly where there is potential for bioaccumulation, this pathway will also need to be considered on residential, commercial and industrial sites. See CCME (2006a) for more details.

The soil and food ingestion pathway must be considered at Tier 2 under all agricultural and natural land use and is not eligible for Tier 2 Guideline Adjustment. SSRA must consider all aspects of potential soil and food ingestion for critical receptors at the site. For substances that bioaccumulate, this exposure pathway may be important on residential, commercial and industrial sites.

Protection of groundwater for aquatic life

Protection of groundwater for aquatic life must be considered when surface water bodies are present within 300 m of the site. If the direction of groundwater flow has been reliably determined by site-specific groundwater monitoring, this may be limited to 100 m up gradient and 300 m down gradient of the site.

The 300 m radius must be measured from the closest point of the zone of contamination exceeding the aquatic guidelines to closest point of the flood risk area (1 in 100 year flood area) of the water body. Where the flood risk area is not defined, it is up to the professional conducting the assessment to determine the distance to the flood risk area based on site information (e.g., geologic information, high water mark). In the absence of surface water bodies within the specified distance, this pathway may be excluded at Tier 2.

The soil guideline values for the protection of aquatic life are derived by considering leaching, mixing and dilution, together with advective-dispersive transport over a lateral distance of 10 m. Under the Tier 1 approach, this is assumed to be the minimum typical

distance between an operating site or facility and a natural surface water body. Therefore, 10 m represents the minimum separation distance that must be present between the edge of a stable or decreasing plume and the flood risk area of the water body in question for the Tier 1 aquatic guidelines to be applied. Where the site does not meet this condition, it may be necessary to recalculate the Tier 1 objective using a 0 separation distance between the water body and the contaminant.

To use either the 300 m offset for exclusion of aquatic life or the 10 m default for calculation of Tier 1 objectives, the following conditions must be met.

1. Both the 300 m offset for exclusion of aquatic life and the 10 m offset for calculation of Tier 1 guidelines assume a stable or decreasing dissolved contaminant plume. Therefore, application of the offset distance cannot be done before all potential sources have been removed.
2. Where the contaminant is a conservative solute that has little interaction with the soil or geological matrix and has low biodegradation potential (e.g. chloride), the potential for the contaminant to impact the surface water body must be assessed and demonstrated through modeling or monitoring before applying the default distance.
3. Where the Darcy velocity (hydraulic conductivity x hydraulic gradient) is greater than the default value for coarse soils (3×10^{-7} m/s), the use of the 300 m offset for exclusion of groundwater cannot be automatically assumed. In these instances, it must be shown that the site condition is equivalent to or at lower risk than the default scenario at 300 m prior to exclusion of the aquatic life pathway.
4. Where the Darcy velocity is greater than the default for coarse soil or for any coarse textured site located on the flood risk area, the 10 m offset for the calculation of Tier 1 guidelines for aquatic life cannot be automatically used. Tier 2 objectives must be calculated assuming zero separation distance to the aquatic water body, or it must be demonstrated at Tier 2 that the site condition is equivalent to, or at lower risk than, the default scenario for coarse soils prior to applying the Tier 1 aquatic life guidelines.

Options for recalculation of the aquatic pathway or SSRA with respect to the aquatic pathway are available. Certain soil and hydrogeological conditions considered in the modeling are considered to be fixed and stable (see Section 3.3 below), and can therefore be adjusted on a site-specific basis without the requirement for ongoing management. In addition, the distance to a natural surface water body can also be adjusted to reflect the appropriate site-specific value. SSRA based on direct groundwater measurements is possible and requires a more detailed assessment of groundwater quality, flow direction, velocity, detailed contaminant assessment and modeling.

Protection of groundwater for aquatic life may be excluded at Tier 2 if no surface water bodies are present within 300 m of the site. If the pathway is operative, certain soil and groundwater parameters are eligible for Tier 2 Guideline Adjustment. Protection of groundwater for aquatic life is eligible for Tier 2 SSRA.

Protection of groundwater for livestock

Ingestion of groundwater through livestock watering is considered an operative pathway under agricultural land use and in natural areas subject to grazing leases. The derivation of soil guidelines for the protection of groundwater for livestock is based on a leaching, mixing and dilution model that considers certain soil and hydrogeological parameters. Due to the potential to develop surficial dugouts for livestock watering, the pathway cannot be automatically ruled out for the agricultural land use. Where contamination is clearly below the depth that would normally be associated with a surficial dugout and where the underlying groundwater is not suitable for irrigation, it may be possible to rule the pathway out in the event that there is a similar intervening layer between the contaminated aquifer and any aquifer that may be suitable for livestock watering, as defined for the drinking water aquifer.

Certain parameters are considered to be fixed and stable (see Section 3.3 below) and can therefore be adjusted on a site-specific basis without the need for restrictions or management measures. Distance to groundwater user cannot be adjusted at Tier 2, since this would imply a restriction on groundwater use within that distance.

Protection of groundwater for livestock must be considered at Tier 2 under agricultural land use and in natural areas with grazing leases unless there is no suitable aquifer beneath the site and the contaminant is below the depth of a typical excavation for a dugout. Certain soil and groundwater parameters are eligible for Tier 2 Guideline Adjustment, and this pathway is eligible for SSRA as long as the entire aquifer is protected.

Protection of groundwater for irrigation

Use of groundwater for irrigation is considered an operative pathway under agricultural land use. The derivation of soil guidelines for the protection of groundwater for irrigation is based on a leaching, mixing and dilution model that considers certain soil and hydrogeological parameters. This pathway is included in all agricultural scenarios. Due to the potential to develop surficial dugouts for irrigation, the pathway cannot be automatically ruled out for the agricultural land use. Where contamination is clearly below the depth that would normally be associated with a surficial dugout and where the underlying groundwater is not suitable for irrigation, it may be possible to rule the pathway out in the event that there is a similar intervening layer between the contaminated aquifer and any aquifer that may be suitable for irrigation, as defined for the drinking water aquifer.

Certain parameters are considered to be fixed and stable (see Section 3.3 below) and can therefore be adjusted on a site-specific basis without the need for restrictions or management measures. Distance to groundwater user cannot be adjusted at Tier 2, since this would imply a restriction on groundwater use within that distance. Site-specific risk assessment is possible for protection for irrigation but is subject to an increasing level of detail requirements regarding the aquifer dynamics and contaminant characteristics. In addition it must be shown to protect all points within the aquifer of concern.

Protection of groundwater for irrigation must be considered at Tier 2 under agricultural land use unless there is no suitable aquifer beneath the site and the contaminant is below the depth of a typical excavation for a dugout. Certain soil and groundwater parameters are eligible for adjustment at Tier 2. Tier 2 SSRA is possible but it must protect the entire aquifer of concern.

Protection of groundwater for wildlife

Ingestion of water by wildlife is considered an operative pathway under the natural areas land use, and must be considered when there are surface water bodies within 300 m of the site. If the direction of groundwater flow has been reliably determined by site-specific groundwater monitoring, this may be limited to 100 m up gradient and 300 m down gradient of the site.

The 300 m radius is measured from the closest point of the zone of contamination to the closest point of the flood risk area (1 in 100 year flood area) of the water body. The use of the 300 m offset distance is subject to the same restrictions as specified for protection of aquatic life. Namely, the user must assess the following prior to applying the offset limit.

1. The dissolved contaminant plume is stable or decreasing (e.g. all potential sources have been managed) and the offset distance does not have the potential to change with time.
2. Where the contaminant is a conservative solute that has little interaction with the soil or geological matrix and has low biodegradation potential, the potential risk for impact to the water body beyond 300 m must be assessed and demonstrated through modeling or monitoring before applying the default distance.
3. The Darcy velocity is no greater than that of the default for coarse soils (3×10^{-7} m/s). Where the Darcy velocity is greater than that of the default, the user may be able to establish an offset distance that is equally protective.

Provided these exceptions do not apply to the site, this pathway may be excluded at Tier 2.

The soil guideline values for the protection of wildlife watering are derived by considering leaching, mixing and dilution, together with advective-dispersive transport over a lateral distance of 10 m, considered to be the minimum typical distance between an operating site or facility and a natural surface water body. Use of the Tier 1 value for wildlife watering is subject to the same exceptions as those specified for the aquatic life guidelines. Therefore, as with the aquatic life guidelines, the user must determine that the following will not apply to the soil or should recalculate the guidelines at Tier 2 using a zero offset distance:

1. There is a stable or decreasing plume (e.g. a plume where all potential sources have been managed). The offset distance cannot be applied until this is accomplished
2. Where the Darcy's velocity is greater than the default for coarse soil (3×10^{-7} m/s) or for any coarse textured site located on the flood risk area, the 10 m offset for the

calculation of Tier 1 guidelines for wildlife watering cannot be automatically used. Tier 2 objectives must be calculated assuming zero separation distance to the aquatic water body, or it must be demonstrated at Tier 2 that the site condition is equivalent to, or at lower risk than, the default scenario for coarse soils prior to applying the Tier 1 wildlife watering guidelines.

Certain soil and hydrogeological conditions considered in the modeling are considered to be fixed and stable (see Section 3.3 below), and can therefore be adjusted on a site-specific basis without the requirement for ongoing management. In addition, the distance to a natural surface water body can also be adjusted to reflect the appropriate site-specific value. This adjustment must be made if the surface water body is within 10 m of the site.

Protection of groundwater for wildlife watering is applicable under natural area land use, but may be excluded at Tier 2 if no surface water bodies are present within 300 m downgradient of the site. If the pathway is operative, certain soil and groundwater parameters are eligible for Tier 2 Guideline Adjustment. This pathway is also eligible for SSRA.

Other Considerations

Tables 2, 3 and 4 summarize pathways and receptors for consideration in a human health and ecological risk assessment. Table 5 summarizes the human and ecological pathways considered at Tier 1, identifying those that are eligible for exclusion or modification at Tier 2. For more information on other considerations not listed here, the user is referred to CCME (2006a).

Section 3 describes the most common Tier 1 evaluations, but is not meant to be an exhaustive list, particularly where detailed SSRAs are required. In conducting any Tier 2 reassessment, the user must reassess potential for impacts to all pathways and receptors that may be critical to ensure that Tier 2 modifications proposed remain protective of all pathways and receptors.

For detailed site-specific risk assessments, all human health and environmental concerns associated with residual contaminant must be met. Where potential risk associated with any other consideration is greater than that of any pathways or receptors listed here, that must be used in setting the risk based cleanup guidance. Some other concerns not specifically addressed in this list but that must be considered in conducting any detailed risk assessment include:

1. For environmental receptors, Soil Ingestion by Primary Consumers must be considered on all natural, agricultural and residential sites.
2. For environmental receptors, Soil Ingestion by Secondary and Tertiary consumers must be considered on all natural, agricultural and residential sites where the contaminant has the potential to biomagnify or bioconcentrate.
3. For environmental receptors, Nutrient and Energy Cycling. The potential for impact to nutrient and energy cycling must be considered on all natural, agricultural and residential sites.

4. For environmental and human health, Offsite migration potential must be considered for all commercial and industrial sites.
5. For human health, consumption of produce, meat, milk from the contaminated site for all contaminants that have potential to biomagnify or bioconcentrate.
6. For environmental and human health, where soil and food ingestion is a critical pathway of concern, it must be considered on commercial and industrial properties as well. For more guidance, the user is referred to CCME (2006a).
7. For all human health assessments, risk from acute pica events should be evaluated to determine that the assessment is protective of these events. See CCME (2006a) for more information.
8. For all sites where receptor or the nature of land use may be more sensitive than used in default scenarios, these must be evaluated and used in determining risk.
9. Considerations of other risks other than direct toxicity must be evaluated in determining contaminant risk. Other considerations include but are not limited to aesthetics, explosive risk, potential for health or environmental risk in the event of excavation, potential for free phase formation, or damage to utilities or infrastructure. Where risks associated with these concerns are greater than for other pathways, the risk must be assessed and appropriate adjustments made to ensure that the contaminant does not pose an ongoing risk.

3.3 Parameters

As discussed in the foregoing section, Tier 1 soil remediation guideline values pertaining to certain operative exposure pathways may be modified at Tier 2 by the substitution of site-specific values for adjustable parameters. This option is limited to exposure pathways where the determination of Tier 1 guideline values includes fate and transport modeling.

The key site-specific parameters are summarized in Table 6 for the vapour intrusion pathway and the groundwater pathways. Those parameters that are eligible for adjustment at Tier 2 are indicated in the tables. The tables also indicate whether adjustment of the parameters would lead to land or water use restrictions or a requirement for ongoing management. Land and water use restrictions are not eligible for Tier 2 closure.

The use of site-specific parameters at Tier 2 must be supported by adequate site data justifying the selection of the values used. Furthermore, the decision to undertake Tier 2 adjustments is a commitment to increase the "realism" of the modeling. Therefore, the commitment must also be made to ensure an increased certainty in the level of environmental protection offered by the Tier 2 evaluation. Where the effect of an adjustment in one or more parameters is a decrease in the calculated guideline value, the lower site-specific value must be used rather than Tier 1 guidelines. Where measurements are highly variable or uncertain or where insufficient data is available to reliably predict the parameter, the Tier 2 option is not available. Data collection for Tier 2 adjustments must be relevant to the depth and location that is associated with the use in the model and must be sufficient in scope and numbers to account for typical spatial and temporal variability associated with the parameter. Single measurements can never be used for Tier

2 adjustments as they will not account for potential variability. The model parameter used for the Tier 2 adjustment must always represent a conservative estimate based on the variability of in-field measurements. Further discussion of data requirements for Tier 2 modification is presented in Section 4.1.

3.4 Exposure Pathway or Point-of Exposure Measurements

As discussed, certain exposure pathway or point-of-exposure measurements of contaminant concentrations may be used as part of SSRA. In some instances, these modifications may be used in conjunction with models presented herein to improve accuracy of model predictions. Direct exposure pathway measurements requires site-specific risk assessment, including increased data collection, contaminant delineation and long term monitoring requirements that are beyond the scope of this document. However, further discussion of the approach, which may be considered under Tier 2 SSRA, is provided in Appendix D.

4. TIER 2 IMPLEMENTATION

4.1 Additional Data Collection to Support Site-Specific Adjustment of Parameters

Upon entering Tier 2, the proponent will have undertaken an assessment that fulfils, as a minimum, the basic requirements for Tier 1 and provides sufficient additional information to support the decision to proceed to Tier 2. To complete the Tier 2 evaluation, which essentially comprises the substitution of certain site-specific parameters for Tier 1 default assumptions or the exclusion of exposure pathways which are not active at the site, the relevant adjustable parameters must be determined and adequately quantified, and the relevant exposure pathways must be confirmed.

To optimize data collection effort and resources at this stage, the governing exposure pathways (based on the Tier 1 evaluation) will be identified. Not all Tier 2 adjustable parameters will be influential for every exposure pathway and receptor. Therefore depending upon the critical pathway(s), only a subset of the possible parameters may need to be defined on a site-specific basis. However, if the Tier 2 modifications result in a different pathway becoming the governing exposure pathway or potentially becoming a governing pathway, this must be investigated as well. Where Tier 2 modifications are allowed for this pathway, there may be value in characterizing site parameters relevant to those additional exposure pathways.

The decision to undertake Tier 2 adjustments implies a commitment to increase the accuracy of the exposure and risk estimates in light of the available site-specific data. Therefore, the values of all readily quantifiable parameters that are influential with respect to the governing pathway must be determined and applied.

Table 6 summarizes parameters governing the vapour inhalation and groundwater protection pathways, indicating those that can be adjusted at Tier 2. Certain groups of parameters (e.g. soil properties, hydrogeological, parameters etc.) are related and must be measured and adjusted together as a group. Groups of parameters, together with the exposure pathways to which they relate, are given in Table C-2, Appendix C.

Further discussion of the parameters and their recommended method of determination is presented in Appendix C. Some considerations regarding the determination of these parameters are presented below.

Physical soil properties

These properties include soil texture, organic carbon fraction, soil porosity and/or bulk density and soil moisture content. Soil texture will have been determined at the Tier 1 stage. The remaining parameters can be measured and used for Tier 2 adjustments. Sufficient measurements of each parameter must be obtained to establish a representative value for each soil unit or stratum that is relevant to the governing exposure pathway. Sampling must describe spatial and temporal variability associated with the parameter and demonstrate that estimate of risk is conservative based on the sampling variability.

Moisture content may vary seasonally and may also be different beneath buildings. It is necessary to obtain measurements that are representative of long-term, stable conditions and are appropriate to the soils of concern. The sampling methodology must be able to describe seasonal variations in moisture content.

Sampling methodology must target the appropriate depth and spatial locations relative to the model input parameters. For instance, permeability is used in the vapour inhalation model at or near the building foundation and therefore, permeability measurements must represent the condition at the default depths for both slab on grade and basement structures. Sampling protocols must be sufficient to completely describe potential for variability across the entire contaminated area and/or potential area of receptor concern, depending on the needs of the model.

Further details on sampling requirements are provided in Appendix C. As noted previously, an understanding of the exposure pathways and associated fate and transport processes is necessary to identify the dominant soil type for each exposure pathway.

Parameter determination will also need to account for the way it is applied within the model. For instance, soil vapour permeability is related to soil texture, porosity and moisture content and is therefore not commonly measured independently. Since it may vary significantly between closely-spaced locations, a stable, long-term value representative of a stratigraphic unit as a whole, should be determined.

Hydrogeological conditions

Hydrogeological conditions include depth to groundwater table, hydraulic conductivity, and hydraulic gradient; these parameters are obtained from a site-specific groundwater investigation. The vertical separation between the lower limit of contaminated soil and the groundwater table is also relevant to the groundwater pathways.

Where the point of compliance is at some distance from the contaminated site, hydrogeological parameters must be representative of the conditions both on-site and along the groundwater transport pathway. For instance, where the aquatic receptor is being assessed, Tier 2 modifications must consider the relevant pathway between the aquatic receptor and the contaminant source.

Site dimensions and distances to receptors

Contaminant source length and width are adjustable parameters with respect to the soil-to-groundwater pathway. Length and width dimensions are measured parallel and perpendicular to the principal groundwater flow direction, respectively. Site-specific distances from the edge of the contamination to receptor locations may also be parameters that can be adjusted at Tier 2. Three types of receptor distance measurements do not lead to land or water restrictions and are allowed at Tier 2, namely,

1. Distance to fixed surface water bodies,
2. Distance from a contaminant plume to a more sensitive land use. For instance, if the contaminant is on an industrial site with residential zoning nearby, the distance

between the edge of the contaminant plume and the residential zoning may be considered at Tier 2 Guideline Adjustment to determine if the residential land use offsite is protected or,

3. Distance from a contaminant plume to a building that is more sensitive than assumed at Tier 1. For example, lateral offsets between the contaminant plume and the building may be employed at Tier 2 for a building with an earthen floor basement provided that generic default building parameters are used to calculate the objectives at all other points on the site.

Secondary user-adjustable parameters

A number of other parameters are influential but may not be well-suited to Tier 2 adjustment due to the fact that they are not readily measured, they cannot be controlled in a generic way or they lead to site-specific restrictions that would require use of Exposure Control. These include lateral distance to a building (inhalation receptor) and building characteristics (foundation configuration, presence of cracks, air exchange rate, etc.). These are indicated in Table 6 and identified as not being adjustable at Tier 2.

4.2 Tier 2 Guideline Adjustment based on Site-specific Parameters

Recalculation of the Tier 1 guideline values to determine site-specific Tier 2 values (Tier 2 Guideline Adjustment) must be performed using the same modeling procedures (i.e. equations, algorithms, models) and default parameters and assumptions used in the derivation of the Tier 1 values, with the exception of the parameters for which a site-specific substitution is being made. This requirement applies to the determination of both soil and groundwater objectives. I

In deciding to employ guideline adjustment, the proponent makes a commitment to reassess all appropriate parameters where the model is sensitive to changes even when changes to the default parameter may result in significantly more stringent guidelines. Therefore, it may be necessary to conduct a sensitivity analysis before proceeding to a field assessment to determine which parameters may be of importance.

Where typical field measurements will lead to less stringent guidelines, but where the value is difficult to verify in the field due to temporal variations, the measurement may not be necessary if it can be readily justified. For instance, due to the temporal variability in moisture content, it is difficult to accurately determine this measurement without the use of long-term monitoring in the field. However, it may be possible to substitute a default moisture content scenario if it is shown to be a conservative estimate.

Where it is not appropriate to use the reference models (e.g. if site-specific conditions invalidate the original model, or if the proponent selects a different model based on preference or site-specific technical considerations) a more detailed SSRA will be required. Part A, Section 5 provides a brief overview of SSRA.

4.2.1 Recalculation of soil and groundwater objectives

Once site-specific parameters have been determined and the applicability of Tier 2 for the subject site and governing exposure pathway(s) has been verified, Tier 2 soil guidelines are calculated in accordance with the methods described in Appendix C.

Typical ranges of potential adjustment are provided in Table C-1, Appendix C, for the primary adjustable parameters based on conditions expected to occur in Alberta. Where it is possible to measure values outside the range presented here for many of the parameters of interest, care should be taken to ensure the parameter is sufficiently representative and conservative. Where the remediation guideline becomes less stringent with parameter measurements outside the range, it is possible to estimate the limit of the value from the model calculation using the limits of the range provided without proceeding to the SSRA option. For example, the minimum permeability range noted is 10^{-12} cm^2. Where field measurements verify that the permeability of the soil is consistently lower than this value, a guideline value using 10^{-12} cm^2 as an input into the model would be appropriate as a Tier 2 Guideline Adjustment value.

Groups of related parameters are identified in Table C-2, Appendix C, together with the corresponding pathway(s) to which they pertain. These must always be measured as a group when proceeding to Tier 2.

4.2.2 Determination of governing objectives

The governing Tier 2 objective is the lowest of the applicable exposure pathway objectives following model adjustment or pathway exclusion. Exposure pathways other than the governing pathway at Tier 1 may become critical, once the adjustment is made. This outcome may limit the amount by which the Tier 2 objective can vary from the Tier 1 guideline, unless the new governing value is also eligible for Tier 2 adjustment.

4.3 Tier 2 Decision and Management

The Tier 2 decision process is illustrated schematically by the lower part of the flow diagram presented in Figure 3. The process consists of a number of decision nodes. The decision process and criteria at each node are discussed in the following paragraphs.

4.3.1 Comparison of conditions with identified Tier 2 objectives

Initially the measured contaminant concentrations are compared with the adjusted numerical objectives established using Tier 2 Guideline Adjustment. If no exceedances are found at this point, the site can be considered to be in compliance with Tier 2 and no further action is necessary. If exceedances are found, remediation to the Tier 2 objective or Exposure Control is required. In some instances, the proponent may reassess whether the site requires more detailed adjustments than allowed via the guideline adjustment pathway and proceed to a more detailed SSRA, as outlined in Figure 3.

4.3.2 Assessment of opportunity for Exposure Control

Since the options for including site-specific information that may be input into the models at Tier 2 are limited, the guideline adjustment option does not capture all site-

specific circumstances that may be important in accounting for exposure risk. Additional site-specific factors that may exist and are not accounted for in Tier 2 guideline adjustment may be accounted for using a more detailed Tier 2 SSRA to obtain site closure.

Exposure Control is also an option but will not lead to regulatory closure. Examples of site-specific exposure control options include:

- site-specific, manageable human receptor characteristics, such as frequency of exposure
- present building location and configuration
- restrictions on human access
- nature and location of existing water use and opportunity to manage future use
- use of engineered controls (e.g. physical or chemical barriers, hydraulic controls)

These options all require a commitment to ongoing site management and ongoing risk management plans. It is the responsibility of the proponent to ensure that these remain in place for as long as the risk is still present at the site (e.g. until the site meets unconditional risk-based guidelines). If site-specific factors are not assessed as having the potential for mitigating exposure, or if exposures could not otherwise be managed, Exposure Control will not be considered viable and the proponent must return to the Tier 1 or Tier 2 approach.

If there is an opportunity for Exposure Control, the proponent should assess the costs and benefits and the impact of restrictions prior to making the decision to proceed. Detailed site-specific human health and ecological risk assessments are considerably more intensive with respect to investigation, data requirements, computation and modeling, and regulatory review, than Tier 2 adjustments or screening level risk assessments. Details of the requirements of a site-specific risk assessment are contained in various available guidance documents and are summarized in Section 5 of Part A of this document.

All exposure control scenarios require acceptance by all affected stakeholders. Guidance with respect to land and water use restrictions and other conditions has been provided in previous sections of this document. If the associated restrictions are not likely to be accepted by stakeholders, the proponent must return to the Tier 1 or Tier 2 approach.

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TABLE 1 EXAMPLES OF CONDITIONS UNDER WHICH TIER 1 DOES NOT APPLY

CONDITION	RESPONSE REQUIRED
Land/water use not captured by generic Tier 1 land uses	Site-specific risk assessment
Exposure pathway is present that is not considered at Tier 1 for the land use	Add exposure pathway (Tier 1 or Tier 2) or proceed to site-specific risk assessment
Human receptors spend more time at the site on average, or receive higher levels of exposure than assumed at Tier 1 for the land use (e.g. higher produce consumption from site)	Tier 2 Guideline Adjustment or site-specific risk assessment or apply more conservative land use at Tier 1
Ecological receptors with high sensitivity	Site-specific risk assessment to ensure sensitive species are protected level
Atypical building construction (earthen floors, crawlspace, low air exchange, etc.)	Generally Tier 2 Guideline Adjustment but may require more detailed site-specific risk assessment
Surface water body within 10 m of contamination	Tier 2 Guideline Adjustment or site-specific risk assessment
Contaminated groundwater in contact with stagnant surface water body	Site-specific risk assessment
Coarse sand/gravel soils with Darcy velocity greater than the default velocity (3×10^{-7}). This may occur for sites with high hydraulic conductivity (> 320 m/y) or where groundwater gradients are greater than those used in the default Tier 1 guidelines (0.028 m/m).	Tier 2 Guideline Adjustment or site-specific risk assessment
Contaminated soil source within 30 cm of existing building foundation or contaminated groundwater or capillary fringe that has potential to be within 30 cm of the building (based on potential for seasonal groundwater fluctuation).	Conduct Tier 2 Guideline Adjustment for the vapour inhalation pathway using a default attenuation coefficient of 0.01 (dilution factor of 100) or proceed to site-specific risk assessment.
Contamination in fractured bedrock	Site-specific risk assessment

Note: This list is not exhaustive; it is the responsibility of the proponent to identify any conditions that may violate the underlying assumptions of Tier 1 and ensure alternate remediation values meet human health and ecological protection objectives.

TABLE 2 EXPOSURE PATHWAYS AND RECEPTORS FOR EACH LAND USE[A]

Pathway	Natural area	Agricultural	Residential/ Parkland	Commercial	Industrial
Direct Contact with Soil	Soil Nutrient and Energy Cycling Processes, Soil Invertebrates, Plants, Wildlife	Humans (all ages), Soil Nutrient and Energy Cycling Processes, Soil Invertebrates, Crops/Plants, Livestock, Wildlife	Humans (all ages), Soil Nutrient and Energy Cycling Processes, Soil Invertebrates, Plants, Wildlife	Humans (all ages), Soil Nutrient and Energy Cycling Processes, Soil Invertebrates, Plants, Wildlife	Humans (all ages), Soil Nutrient and Energy Cycling Processes, Soil Invertebrates, Plants, Wildlife
Direct Contact with Water	Aquatic Life, Plants and Soil Invertebrates	Aquatic Life, Plants and Soil Invertebrates	Aquatic Life, Plants and Soil Invertebrates	Aquatic Life, Plants and Soil Invertebrates	Aquatic Life, Plants and Soil Invertebrates
Indoor Vapour Inhalation	N/A	Humans (all ages)	Humans (all ages)	Humans (all ages)	Humans (adults)
Ingestion of Water	Humans (all ages) Wildlife	Humans (all ages), Livestock, Wildlife	Humans (all ages).	Humans (all ages)	Humans (all ages)
Soil and Food Ingestion	Wildlife	Humans (all ages), Wildlife, Livestock	Humans (all ages), Wildlife	See note B	See note B

A Table 2 represents typical scenarios considered at Tier 1 and does not represent an exhaustive list of pathways and receptors. For more detail, see Table 5 and CCME (2006a).

B Although the pathway is generally not applied, some consideration may be required for substances that biomagnify or bioaccumulate through the food chain. See CCME (2006a) for more details.

TABLE 3 HUMAN HEALTH EXPOSURE PATHWAYS FOR DEVELOPMENT OF SOIL QUALITY GUIDELINES[A]

Pathway	Agriculture	Residential/ Parkland	Commercial	Industrial
- Direct Contact with Soil	All	All	All	All
- Ingestion of Potable Groundwater	Soluble	Soluble	Soluble	Soluble
- Indoor Vapour Inhalation	Volatile (basement and slab-on-grade)	Volatile (basement and slab-on-grade)	Volatile (slab-on-grade)	Volatile (slab-on-grade)
- Consumption of produce, meat, and milk	Required for bioaccumulating; recommended for all	Produce only	None	None
- Offsite migration	None	None	All	All

A Table 3 represents typical scenarios considered at Tier 1 and does not represent an exhaustive list of pathways and receptors. For more detail, see Table 5 and CCME (2006a).
All = pathway is evaluated for all chemicals
Soluble = pathway is evaluated for chemicals for which Alberta or Canadian water quality guidelines have been published, or which have solubility limits exceeding derived water quality objectives
Volatile = pathway is evaluated for chemicals for which the product of the water solubility and unitless Henry's law constant exceed published or derived tolerable concentration or risk-specific concentration
Bioaccumulating – pathway is evaluated for chemicals which may accumulate in biota

TABLE 4 ECOLOGICAL EXPOSURE PATHWAYS FOR DEVELOPMENT OF SOIL QUALITY GUIDELINES

Pathway	Natural	Agricultural	Residential/ Parkland	Commercial	Industrial
- Soil Contact	All	All	All	All	All
- Soil Ingestion: 1° consumers	All	All	Biomagnifying	None	None
- Soil Ingestion: 2° and 3° consumers	Biomagnifying	Biomagnifying	Biomagnifying	None	None
- Nutrient and Energy Cycling	All	All	All	All	All
- Groundwater: Freshwater Life	Soluble	Soluble	Soluble	Soluble	Soluble
- Groundwater: Agricultural (Irrigation & Livestock Watering)	Soluble	Soluble	None	None	None
- Offsite migration	None	None	None	All	All

A Table 4 represents typical scenarios considered at Tier 1 and does not represent an exhaustive list of pathways and receptors. For more detail, see Table 5 and CCME (2006a).
1°, 2° and 3° consumers = The type of consumer refers to trophic levels on the food chain. Primary (1°) consumers may be considered either animals that feed on the plants (e.g. herbivores) or organisms that feed on organic material in the soil (e.g. earthworms). More detail is available in CCME 2006(a).
All = pathway is evaluated for all chemicals
Soluble = pathway is evaluated for chemicals for which Alberta or Canadian water quality guidelines have been published, or which have solubility limits exceeding derived water quality objectives
Volatile = pathway is evaluated for chemicals for which the product of the water solubility and unitless Henry's law constant exceed published or derived tolerable concentration or risk-specific concentration
Biomagnifying – pathway is evaluated for chemicals, which may increase in concentration as they move through a food chain

TABLE 5 EXCLUSION, RE-EVALUATION AND MODIFICATION OF PATHWAYS AT TIER 2

	PATHWAY	OPTIONS
Human Pathways	Direct Contact	Cannot be excluded or modified at Tier 2
	Vapour Inhalation	Can be modified but not excluded at Tier 2
	Protection of Potable Water	Can be modified (soil only) or excluded at Tier 2. For exclusion, DUA must be shown to be isolated from any contamination by a natural geologic barrier.
	Ingestion of Produce, Meat and Milk	Cannot be modified via Tier 2 Guideline Adjustment. Where detailed site-specific risk assessment is required, this pathway must be evaluated for all contaminants that have potential to biomagnify. Must be evaluated if there is potential for local produce, meat and/or milk to form a significant portion of the diet.
	Acute Exposure (pica events[a])	Used as a check in guidelines development. Where detailed site-specific risk assessment is required, the endpoints must be screened against this scenario to ensure protection for all potential acute exposure events.
	Inhalation of Particulates	Particulate exposure has been assessed within Tier 1 guidance. For detailed site-specific risk assessments where this has potential to become a controlling pathway, this factor must be considered and monitoring must be comprehensive enough to include screening of this pathway.

	PATHWAY	OPTIONS
Ecological Pathways	Direct Contact	Cannot be excluded or modified via Tier 2 Guideline Adjustment; may be eligible for Tier 2 site-specific risk assessment for certain chemicals.
	Soil and Food Ingestion (livestock/wildlife)	Cannot be excluded or modified via Tier 2 Guideline Adjustment. For detailed site-specific risk assessment, endpoints must be screened to ensure protection of: • primary consumers at the site-specific level where populations may be more sensitive than in the default case, and • secondary and tertiary consumers where contaminants may biomagnify.
	Protection of Aquatic Life	Can be modified at Tier 2. Can be excluded at Tier 2 if there is no surface water body within 300m down gradient or 100m up gradient. Exceptions exist for conservative substances.
	Livestock Watering	Can be modified (soil only) at Tier 2; can only be excluded at Tier 2 if there is no suitable aquifer or the aquifer can be shown to be isolated from any contamination
	Irrigation Water	Can be modified (soil only) at Tier 2; can only be excluded at Tier 2 if there is no suitable aquifer or the aquifer can be shown to be isolated from any contamination
	Wildlife Watering	Can be modified at Tier 2. Can be excluded at Tier 2 if there is no surface water body within 300m down gradient or 100m up gradient. Exceptions exist for conservative substances,
	Nutrient and Energy Cycling	Used as a check for natural, agricultural and residential sites. Where detailed site-specific risk assessment is required, endpoints must be screened to ensure protection for nutrient and energy cycling.
Other Considerations	Offsite migration	Potentially applies to both human and ecological pathways. Cannot be modified or changed at Tier 2, but may be excluded if there is no potential for more sensitive land uses in the vicinity of the site. Where detailed site-specific risk assessment is required, must be screened for all commercial and industrial properties.
	Receptor sensitivity	Potentially applies to human and ecological exposure pathways. Where receptor sensitivity is greater than assumed in the Tier 1 generic land use description, Tier 2 is required to ensure that guidelines are protective for sensitive receptors.
	Risks other than direct toxicity.	May include factors such as aesthetics, explosive risk, worker exposure risks, potential for free phase formation damage to infrastructure, land management considerations etc. For detailed site-specific risk assessments, endpoints must be screened to ensure that they do not pose other risks to human health and the environment.
	Contaminant discharge into a stagnant water body.	In addition to other considerations, assessment of potential for long-term accumulation in the water body through the entire time of contaminant release must be considered.

[a] The deliberate ingestion of soil by young children is often referred to as a pica event. In this instance, the term is used more broadly to define any event that would result in a high level acute exposure to a contaminant that may be toxic. It is generally assumed that a high acute exposure scenario will be most applicable to young children. This type of exposure is generally used as a check in the guidelines development. For SSRA, this check must be done to ensure the approach remains protective of acute exposure events.

TABLE 6 RESTRICTIONS ASSOCIATED WITH TIER 2 MODEL PARAMETERS[a]

Parameter	Land/Water Use Restrictions	Management Requirements	Tier at Which Parameter Can be Adjusted
Soil dry bulk density	No	None	Tier 2
Soil moisture content	No	None	Tier 2
Soil vapour permeability	No	None	Tier 2
Organic carbon fraction	No	None	Tier 2
Depth to contamination	No, with exceptions[b]	Assurance required that contamination will remain at specified depth if direct exposure pathway are excluded[b]	Tier 2 (adjustments to vapour inhalation and groundwater transport) Exposure Control (direct exposure pathway exclusion)
Depth to groundwater	No	None	Tier 2
Thickness of contamination	No	None	Tier 2
Hydraulic conductivity	No	None	Tier 2
Hydraulic gradient	No	None	Tier 2
Infiltration (recharge) rate	No	None	Cannot be adjusted at this time, with one exception[c]
Distance to potable water user	Yes	No potable water use within specified distance[d]	Only applies to Exposure Control due to requirement for water use restriction.
Distance to livestock watering	Yes	No livestock watering within specified distance[d]	Only applies to Exposure Control due to requirement for water use restriction.
Distance to irrigation water	Yes	No irrigation water use within specified distance[d]	Only applies to Exposure Control due to requirement for water use restriction.
Distance to surface water	No	None	Tier 2
Dimensions of contamination	No	None	Tier 2
Distance to building	Yes	No construction within management zone	Only applies to Exposure Control due to requirement for construction[e]
Building parameters	Yes	No changes to building configuration or mechanical systems	Only applies to Exposure Control due to requirement for construction[f]
Human receptor characteristics	Yes	Cannot be adjusted.	Only applies to Exposure Control.
Human exposure factors	Yes	Administrative controls (land use or access restrictions)	Only applies to Exposure Control due to requirement for construction. Where receptors may experience more exposure than the default Tier 1 case, adjustment is made at Tier 2.
Chemical properties and toxicity reference values	No	None	Cannot be adjusted[g]

a – Requirements for the measurement of model parameters are outlined in Appendix C.

b – Depth to contamination can be used to adjust but not exclude the vapour transport and groundwater models. Use of this parameter in sites that may be re-graded or use of depth to contamination to exclude direct exposure pathways generally leads to management restrictions. For Petroleum Hydrocarbons where management requirements are built into the Tier 1 guidance, this assurance can be assumed if soil management guidelines are directly adopted and contaminants are below 3 m depth.

c – The exception is that the fine soil recharge rate can be applied if there is a sufficient continuous layer of fine soil overlying a coarse aquifer (see Appendix C).

d – Point of compliance for closure is the entire Domestic Use Aquifer which may be used for the specified water use.

e – An exception is made for earthen floor buildings. In this case, distance to building may be applied to the existing building without use of Exposure Control provided the dimensions of the contaminant zone are stable or decreasing and the remainder of the site is assessed against the generic building parameters.

f- Modeling for an existing building more sensitive than the default for the land use (e.g. building with earthen floor) may be undertaken at Tier 2, provided modeling is also undertaken for the default building and the more conservative of the results applied.

g – Some specific exceptions exist but only where the chemical is present in a different form from that which is assumed in the default scenario (e.g. different valence state or part of a stable molecule). Where the chemical is stable in a form for which guidance already exists (e.g. use of barite vs barium), the stable form can be adopted. Where the form in question is more toxic than the default form, the site must be screened for protection against the more sensitive form (e.g. CrVI vs CrIII).

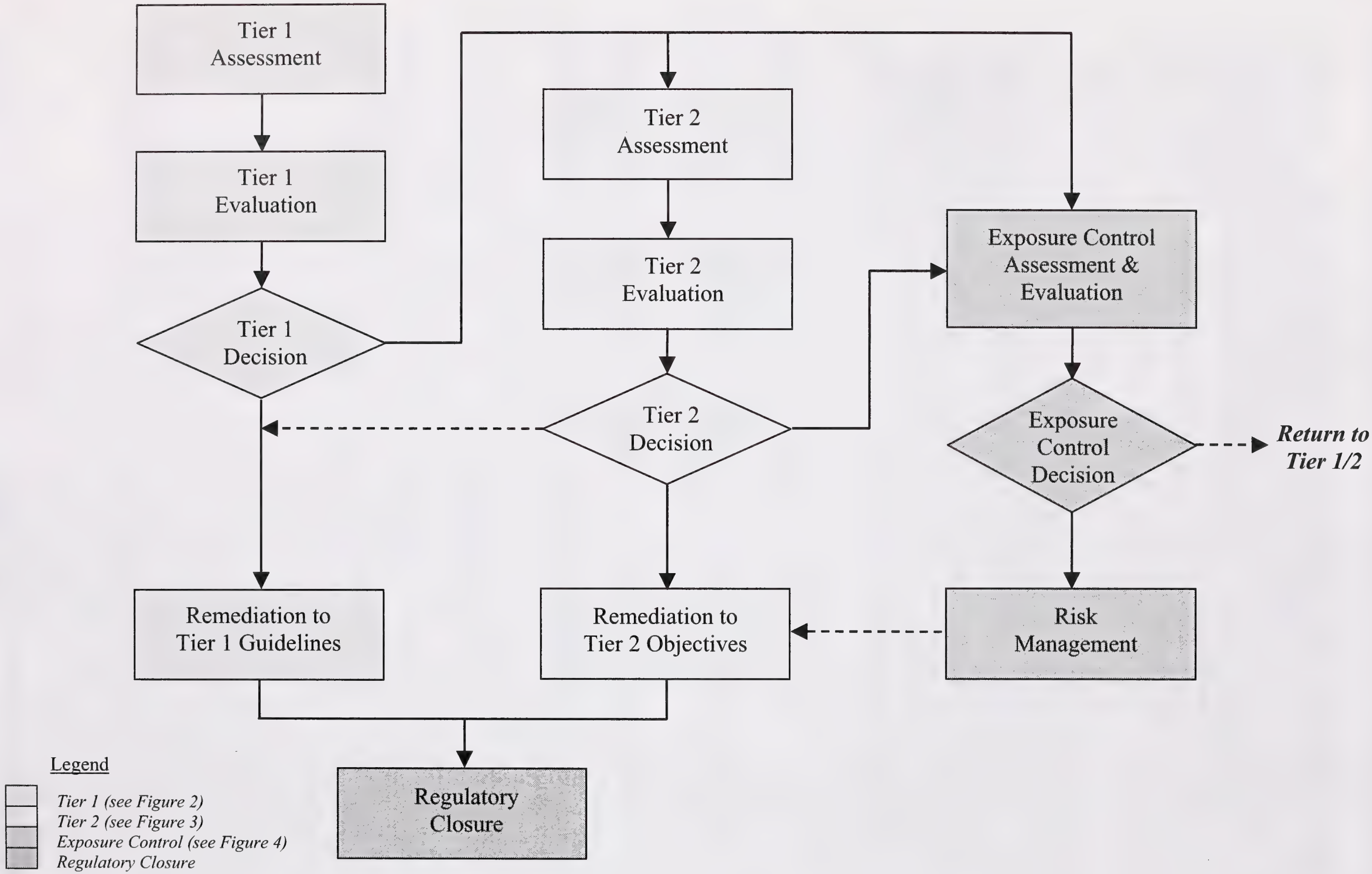

Figure 1: Implementation Framework for Tier 1, Tier 2 and Exposure Control Guidelines

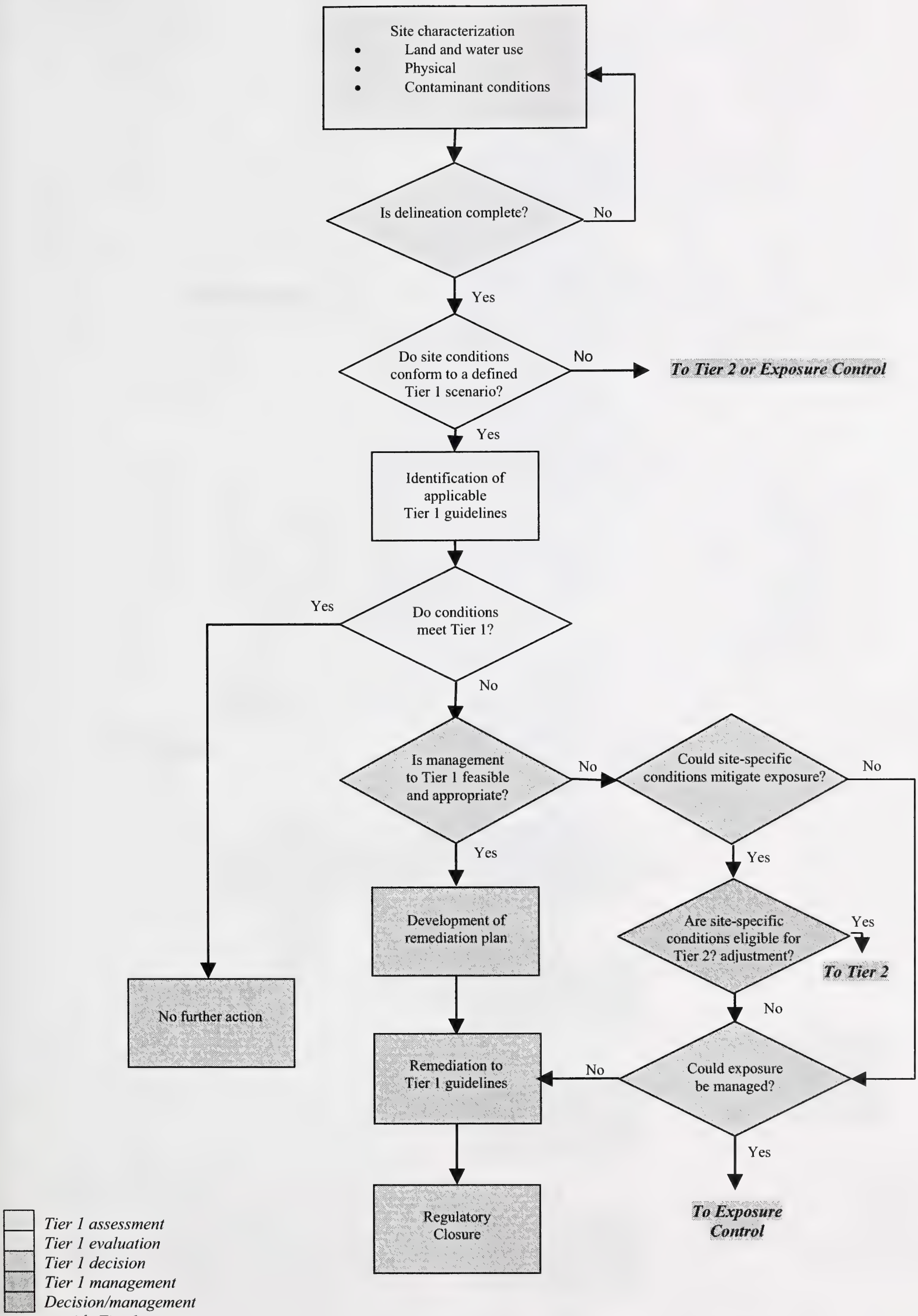

Figure 2: Expanded Flow Diagram – Tier 1

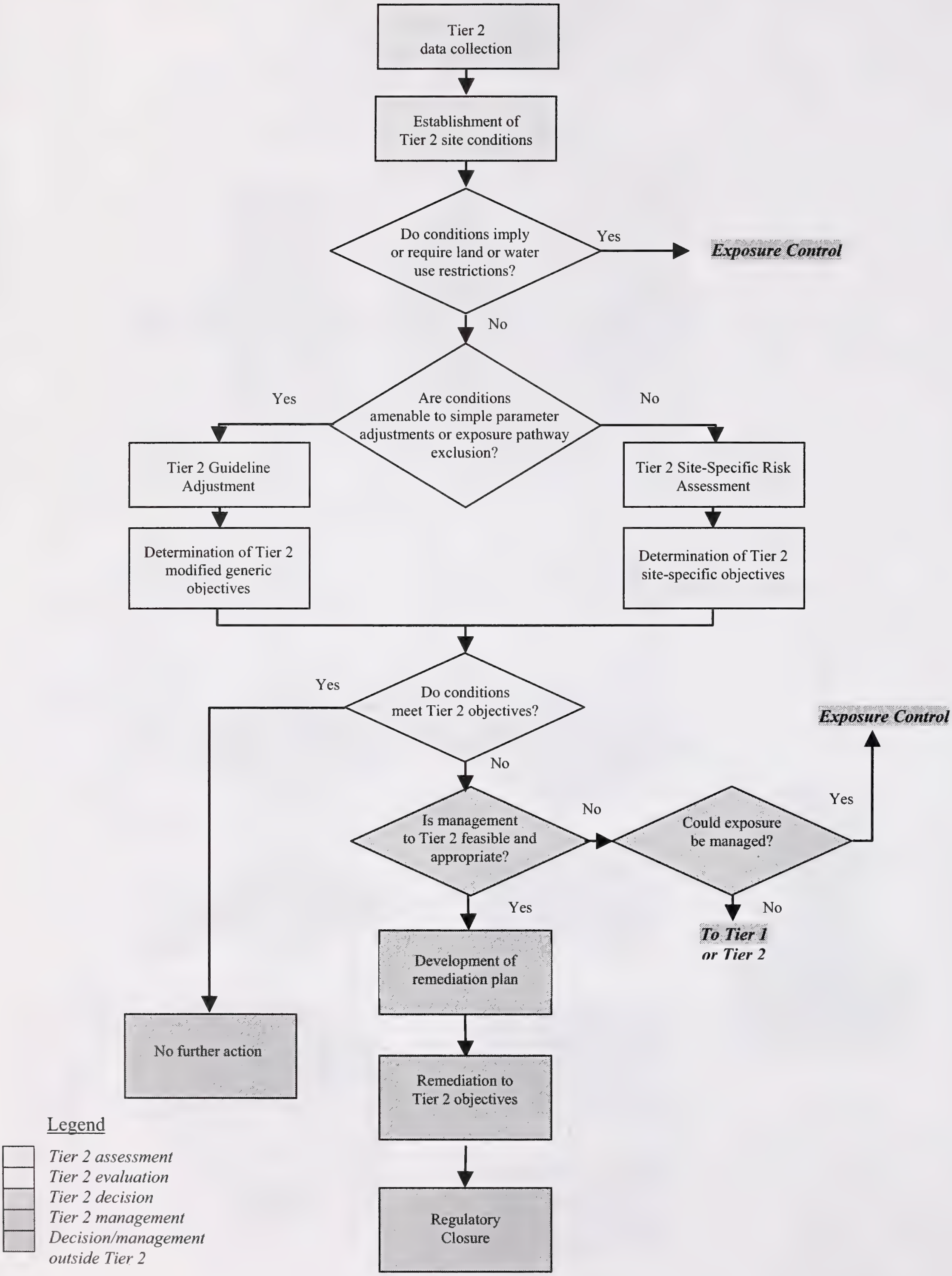

Figure 3: Expanded Flow Diagram – Tier 2

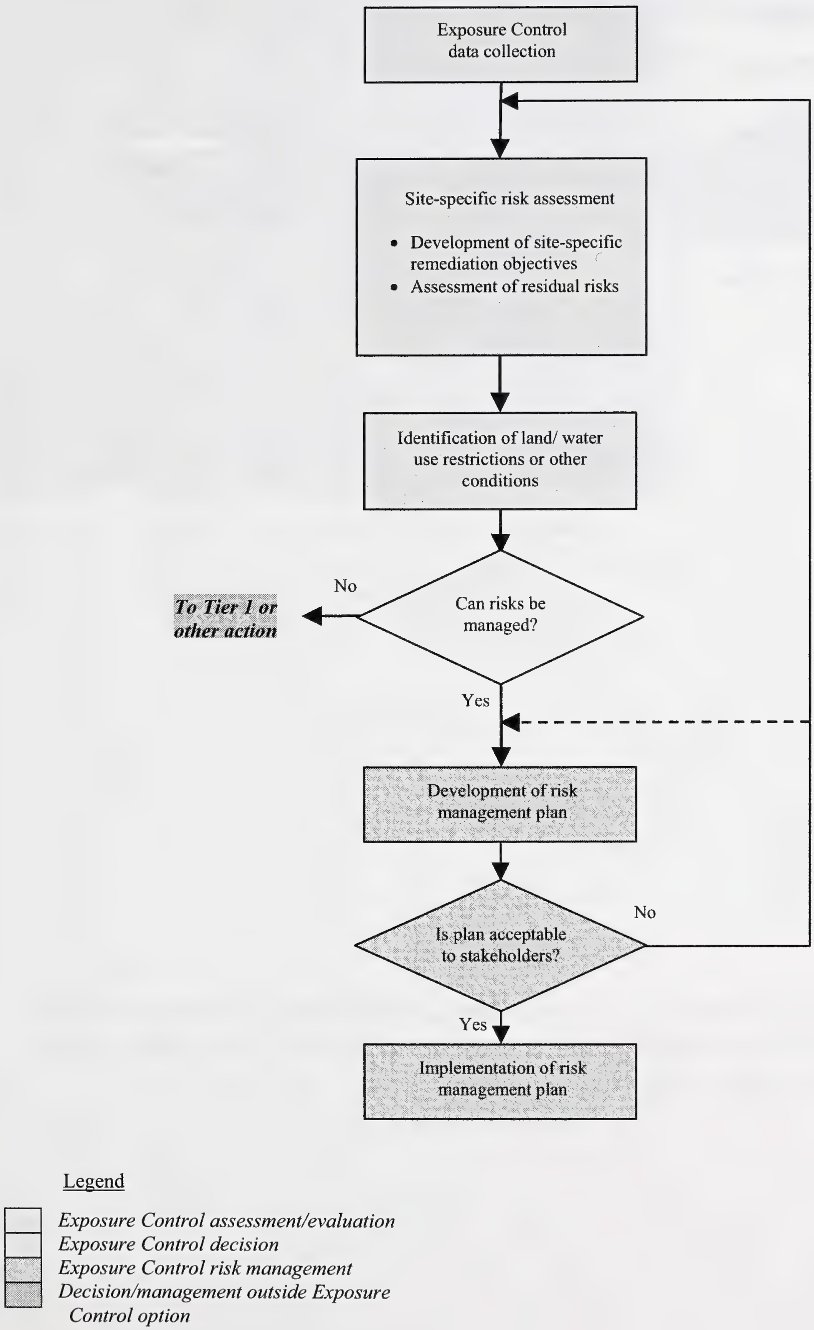

Figure 4: Expanded Flow Diagram – Exposure Control

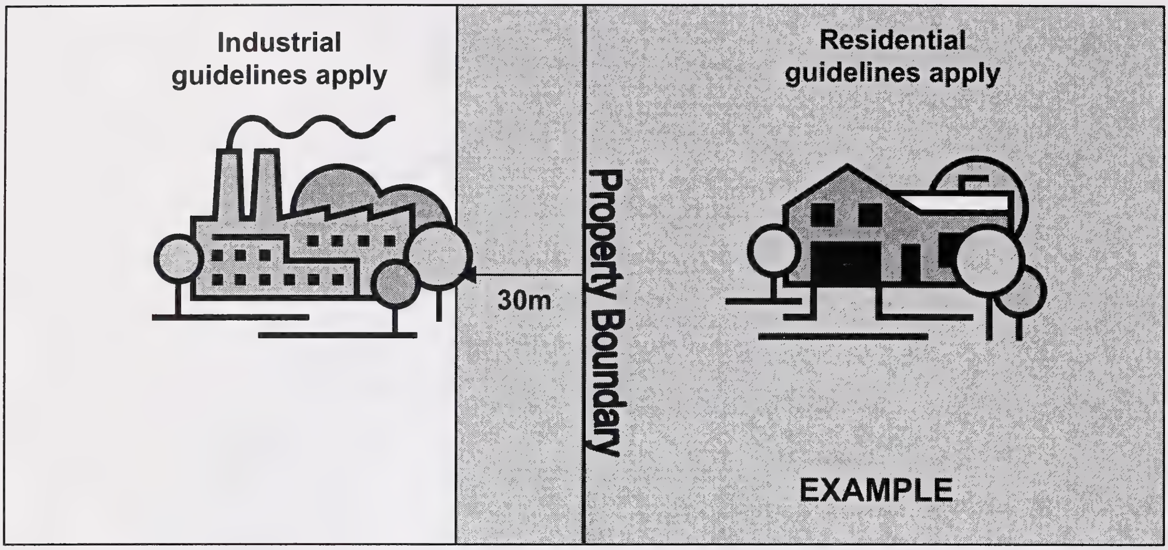

Figure 5: Example of the 30 m buffer zone for the more sensitive land use. The diagram is for illustration purposes and can be applied for any land use scenario where a more sensitive land use is adjacent to a less sensitive land use.

APPENDIX A - PROTOCOLS FOR CALCULATING ALBERTA TIER 1 SOIL AND GROUNDWATER REMEDIATION GUIDELINES

LIST OF TABLES

Table A-4. Building Parameters

			Residential Basement		Residential Slab-on-Grade		Commercial Slab-on-Grade		
Parameter	**Symbol**	**Unit**	**Other Hydrocarbons**	**Petroleum Hydrocarbons**	**Other Hydrocarbons**	**Petroleum Hydrocarbons**	**Other Hydrocarbons**	**Petroleum Hydrocarbons**	**Notes**
Adjustment Factor			1	10	1	10	1	10	1,2
Building Length	L_B	*cm*	1,225	1,225	1,225	1,225	2,000	2,000	
Building Width	W_B	*cm*	1,225	1,225	1,225	1,225	1,500	1,500	
Building Height (including basement)	H_B	*cm*	360	360	360	360	300	300	2
Area of Substructure	A_B	*cm²*	2.7×10^6	2.7×10^6	1.5×10^6	1.5×10^6	3.0×10^6	3.0×10^6	
Thickness of Floor Slab	L_{crack}	*cm*	11.25	11.25	11.25	11.25	11.25	11.25	
Depth of Floor Slab Below Ground	Z_{crack}	*cm*	244	244	11.25	11.25	11.25	11.25	
Distance from Source to Slab:	L_T	*cm*							
surface soil			30	30	30	30	30	30	
subsoil			30	30	139	139	139	139	
Crack Area	A_{crack}	*cm²*	994.5	994.5	994.5	994.5	1,846	1,846	
Crack Length	X_{crack}	*cm*	4,900	4,900	4,900	4,900	7,000	7,000	
Air Exchange Rate	ACH	*exch/hr*	0.5	0.5	0.5	0.5	0.9	0.9	2
Pressure Differential	ΔP	*g/cm·s²*	40	40	40	40	20	20	

Notes:
All parameters values from CCME (2006a) except as noted
1. *An application factor of 10 is applied to the calculation for hydrocarbons only to account for empirical evidence of reduction in predicted indoor air concentrations. No data are available to support such a correction for non-hydrocarbons, and accordingly no application factor is used for non-hydrocarbons.*
2. *From CCME (2007a)*

Table A-5. Livestock and Wildlife Receptor Characteristics

Parameter	Symbol	Unit	Livestock (Cow) [a]	Wildlife (Meadow Vole)
Body Weight	BW	kg	550 [a]	0.017 [c]
Soil Ingestion Rate	SIR	kg/d	0.747 [b]	0.000058 [d]
Water Ingestion Rate	WIR	L/d	100 [a]	0.00357 [a]

Notes:
a. *CCME (2006a)*
b. *NRC (1996)*
c. *USEPA (1993)*
d. *Calculated; see text*

Table A-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Hydrocarbons										
Benzene	81	EC (2004a)	0.225	EC (2004a)	8.80E-02	EC (2004a)	1780	Gustafson et al (1997)	1	BCMELP (1996)
Toluene	234	EC (2004b)	0.274	EC (2004b)	8.70E-02	EC (2004b)	515	Gustafson et al (1997)	0.288	BCMELP (1996)
Ethylbenzene	537	EC (2004b)	0.358	EC (2004b)	7.50E-02	EC (2004b)	152	Gustafson et al (1997)	0.312	BCMELP (1996)
Xylenes	586	EC (2004b)	0.252	EC (2004b)	7.80E-02	EC (2004b)	198	Gustafson et al (1997)	0.501	BCMELP (1996)
Styrene	461	Gustafson et al (1997)	0.123	Gustafson et al (1997)	7.10E-02	Gustafson et al (1997)	300	Gustafson et al (1997)		
F1									1.95	CCME (2007a)
F2									4.79	CCME (2007a)
Aliphatic C_6-C_8	3,981	Gustafson et al (1997)	50	Gustafson et al (1997)	5.00E-02	CCME (2006a)	5.4	CCME (2007a)		
Aliphatic $C_{>8}$-C_{10}	31,623	Gustafson et al (1997)	80	Gustafson et al (1997)	5.00E-02	CCME (2006a)	0.43	CCME (2007a)		
Aliphatic $C_{>10}$-C_{12}	251,189	Gustafson et al (1997)	120	Gustafson et al (1997)	5.00E-02	CCME (2006a)	0.034	CCME (2007a)		
Aliphatic $C_{>12}$-C_{16}	5.01E+06	Gustafson et al (1997)	520	Gustafson et al (1997)	5.00E-02	CCME (2006a)	0.00076	CCME (2007a)		
Aliphatic $C_{>16}$-C_{21}	6.31E+08	Gustafson et al (1997)	4900	Gustafson et al (1997)	5.00E-02	CCME (2006a)	0.0000025	CCME (2007a)		
Aliphatic $C_{>21}$-C_{34}										
Aliphatic $C_{>34}$										
Aromatic $C_{>8}$-C_{10}	1,585	Gustafson et al (1997)	0.48	Gustafson et al (1997)	5.00E-02	CCME (2007a)	65	CCME (2007a)		
Aromatic $C_{>10}$-C_{12}	2,512	Gustafson et al (1997)	0.14	Gustafson et al (1997)	5.00E-02	CCME (2007a)	25	CCME (2007a)		
Aromatic $C_{>12}$-C_{16}	5,012	Gustafson et al (1997)	0.053	Gustafson et al (1997)	5.00E-02	CCME (2007a)	5.8	CCME (2007a)		
Aromatic $C_{>16}$-C_{21}	15,849	Gustafson et al (1997)	0.013	Gustafson et al (1997)	5.00E-02	CCME (2007a)	0.65	CCME (2007a)		
Aromatic $C_{>21}$-C_{34}	125,893	Gustafson et al (1997)	0.00067	Gustafson et al (1997)	5.00E-02	CCME (2007a)	0.0066	CCME (2007a)		
Aromatic $C_{>34}$										
Acenapthene	2,818	CCME (2007b)	6.56E-03	CCME (2007b)	4.21E-02	USEPA (1996)	3.9	CCME (2007b)		
Acenaphthylene	5,623	CCME (2007b)	0.000478	CCME (2007b)			16.1	CCME (2007b)		
Anthracene	19,953	CCME (2007b)	0.0015	CCME (2007b)	3.24E-02	USEPA (1996)	0.057	CCME (2007b)		
Fluoranthene	41,687	CCME (2007b)	0.000609	CCME (2007b)	3.03E-02	USEPA (1996)	0.26	CCME (2007b)		
Fluorene	4,898	CCME (2007b)	0.00337	CCME (2007b)	3.63E-02	USEPA (1996)	1.9	CCME (2007b)		
Naphthalene	708	CCME (2007b)	0.020441	CCME (2007b)	5.90E-02	USEPA (1996)	31.7	CCME (2007b)		
Phenanthrene	6,607	CCME (2007b)	0.000609	CCME (2007b)	2.72E-02	USEPA (1996)	1.15	CCME (2007b)		
Pyrene	69,183	CCME (2007b)	0.000466	CCME (2007b)	2.72E-02	USEPA (1996)	1.35	CCME (2007b)		
Benz[a]anthracene	199,526	CCME (2007b)	0.000142	CCME (2007b)	5.01E-02	USEPA (1996)	0.0094	CCME (2007b)		
Benzo[b+j]fluoranthene	93,325	CCME (2007b)	0.000468	CCME (2007b)	2.26E-02	USEPA (1996)	0.00375	CCME (2007b)		

Table A-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Benzo[k]fluoranthene	11,953	CCME (2007b)	0.0000351	CCME (2007b)	2.26E-02	USEPA (1996)	0.0008	CCME (2007b)		
Benzo[g,h,i]perylene	407,380	CCME (2007b)	0.00000597	CCME (2007b)			0.000026	CCME (2007b)		
Benzo[a]pyrene	2,187,762	CCME (2007b)	0.0000478	CCME (2007b)	4.30E-02	USEPA (1996)	0.0016	CCME (2007b)		
Chrysene	125,892	CCME (2007b)	0.004	CCME (2007b)	2.48E-02	USEPA (1996)	0.00415	CCME (2007b)		
Dibenz[a,h]anthracene	1,380,384	CCME (2007b)	0.000000622	CCME (2007b)	2.02E-02	USEPA (1996)	0.00249	CCME (2007b)		
Indeno[1,2,3-c,d]pyrene	1,584,893	CCME (2007b)	0.0000677	CCME (2007b)	1.90E-02	USEPA (1996)	0.000022	CCME (2007b)		
Halogenated Aliphatics										
Vinyl chloride	18.6	USEPA (1996)	1.11	USEPA (1996)	1.06E-01	USEPA (1996)	2760	USEPA (1996)		
1,1-Dichloroethene	65	USEPA (1996)	1.07	USEPA (1996)	1.04E-01	USEPA (1996)	2250	USEPA (1996)		
Trichloroethene	94	USEPA (1996)	0.422	USEPA (1996)	7.90E-02	USEPA (1996)	1100	USEPA (1996)	2.19	CCME (2006d)
Tetrachloroethene	265	USEPA (1996)	0.754	USEPA (1996)	7.20E-02	USEPA (1996)	200	USEPA (1996)		
1,2-Dichloroethane	38	USEPA (1996)	0.0401	USEPA (1996)	1.04E-01	USEPA (1996)	8520	USEPA (1996)		
Dichloromethane	23.74	ORNL (2006)	0.133	ORNL (2006)	1.01E-01	ORNL (2006)	1300	ORNL (2006)		
Trichloromethane	53.0	USEPA (1996)	0.15	USEPA (1996)	1.04E-01	USEPA (1996)	7920	USEPA (1996)		
Tetrachloromethane	152	USEPA (1996)	1.25	USEPA (1996)	7.80E-02	USEPA (1996)	793	USEPA (1996)		
Dibromochloromethane	35	ORNL (2006)	0.032	ORNL (2006)	1.96E-02	ORNL (2006)	2700	ORNL (2006)		
Chlorinated Aromatics										
Chlorobenzene	224	USEPA (1996)	0.152	USEPA (1996)	7.30E-02	USEPA (1996)	472	USEPA (1996)		
1,2-Dichlorobenzene	379	USEPA (1996)	0.0779	USEPA (1996)	6.90E-02	USEPA (1996)	156	USEPA (1996)		
1,3-Dichlorobenzene	434	ORNL (2006)	0.108	ORNL (2006)			125	ORNL (2006)		
1,4-Dichlorobenzene	616	USEPA (1996)	0.0996	USEPA (1996)	6.90E-02	USEPA (1996)	73.8	USEPA (1996)		
1,2,3-Trichlorobenzene	No data, assumed to be equal to other trichlorobenzene isomers									
1,2,4-Trichlorobenzene	1,659	USEPA (1996)	0.0582	USEPA (1996)	3.00E-02	USEPA (1996)	49	ORNL (2006)		
1,3,5-Trichlorobenzene	No data, assumed to be equal to other trichlorobenzene isomers									
1,2,3,4-Tetrachlorobenzene	No data, assumed to be equal to other tetrachlorobenzene isomers									
1,2,3,5-Tetrachlorobenzene	No data, assumed to be equal to other tetrachlorobenzene isomers									
1,2,4,5-Tetrachlorobenzene	1,186	ORNL (2006)	0.0409	ORNL (2006)	2.11E-02	ORNL (2006)	0.595	ORNL (2006)		

Table A-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Pentachlorobenzene	32,148	USEPA (1996)	0.0287	ORNL (2006)	5.70E-02	ORNL (2006)	0.831	ORNL (2006)		
Hexachlorobenzene	80,000	USEPA (1996)	0.0541	USEPA (1996)	5.42E-02	USEPA (1996)	6.2	USEPA (1996)		
Dichlorophenol	718	ORNL (2006)	0.0000895	ORNL (2006)	3.46E-02	ORNL (2006)	4500	ORNL (2006)		
Trichlorophenol	1,186	ORNL (2006)	0.0000662	ORNL (2006)	2.91E-02	ORNL (2006)	1200	ORNL (2006)		
Tetrachlorophenol	2,002	ORNL (2006)	0.000361	ORNL (2006)	2.17E-02	ORNL (2006)	23	ORNL (2006)		
Pentachlorophenol	2,500	ORNL (2006)	1.00E-06	ORNL (2006)	5.60E-02	ORNL (2006)	14	ORNL (2006)		
Dioxins & Furans [2]										
PCBs [2]										
Pesticides										
Aldicarb	32	ORNL (2006)	5.39E-05	ORNL (2006)	3.05E-02	ORNL (2006)	6030	ORNL (2006)		
Aldrin	106,000	ORNL (2006)	0.0018	ORNL (2006)	1.32E-02	ORNL (2006)	0.017	ORNL (2006)		
Atrazine	230	ORNL (2006)	9.65E-08	ORNL (2006)			35	ORNL (2006)		
Azinphos-methyl	231	SRC (2006) [1]	9.96E-07	SRC (2006)			20.9	SRC (2006)		
Bendiocarb	21	SRC (2006) [1]	1.63E-06	SRC (2006)			260	SRC (2006)		
Bromoxynil	435	ORNL (2006)	5.40E-09	ORNL (2006)	2.01E-02	ORNL (2006)	130	ORNL (2006)		
Carbaryl	242	ORNL (2006)	1.78E-07	ORNL (2006)	2.78E-02	ORNL (2006)	110	ORNL (2006)		
Carbofuran	71	ORNL (2006)	1.26E-07	ORNL (2006)			320	ORNL (2006)		
Chlorothalonil	2,392	ORNL (2006)	8.18E-05	ORNL (2006)			0.6	ORNL (2006)		
Chlorpyrifos	6,829	ORNL (2006)	0.00012	ORNL (2006)			1.12	ORNL (2006)		
Cyanazine	124	ORNL (2006)	1.21E-10	ORNL (2006)			170	ORNL (2006)		
2,4-D	29	ORNL (2006)	1.45E-06	ORNL (2006)	2.31E-02	ORNL (2006)	677	ORNL (2006)		
DDT	794,328	EC (1999a)	3.40E-04	ORNL (2006)	1.37E-02	ORNL (2006)	0.0055	ORNL (2006)		
Diazinon	1,337	ORNL (2006)	4.62E-06	ORNL (2006)	2.06E-02	ORNL (2006)	40	ORNL (2006)		
Dicamba	29	ORNL (2006)	8.91E-08	ORNL (2006)			8310	ORNL (2006)		
Dichlofop-methyl	17,092	SRC (2006) [1]	8.21E-05	SRC (2006)			0.8	SRC (2006)		
Dieldrin	10,600	ORNL (2006)	0.000409	ORNL (2006)	1.25E-02	ORNL (2006)	0.25	ORNL (2006)		
Dimethoate	25	ORNL (2006)	4.29E-09	ORNL (2006)			25000	ORNL (2006)		
Dinoseb	3,544	ORNL (2006)	1.86E-05	ORNL (2006)			52	ORNL (2006)		

Table A-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
Diquat	1,933	ORNL (2006)	5.81E-12	ORNL (2006)			708000	ORNL (2006)		
Diuron	136	ORNL (2006)	2.06E-08	ORNL (2006)			42	ORNL (2006)		
Endosulfan	22,000	ORNL (2006)	0.00266	ORNL (2006)	1.15E-02	ORNL (2006)	0.45	ORNL (2006)		
Endrin	10,811	USEPA (1996)	0.000308	USEPA (1996)	1.25E-02	USEPA (1996)	0.25	USEPA (1996)		
Glyphosate	19	ORNL (2006)	1.67E-17	ORNL (2006)	4.37E-02	ORNL (2006)	12000	ORNL (2006)		
Heptachlor epoxide	9,528	USEPA (1996)	0.0447	USEPA (1996)	1.12E-02	USEPA (1996)	0.18	USEPA (1996)		
Lindane	1,352	USEPA (1996)	0.000574	USEPA (1996)	1.42E-02	USEPA (1996)	6.8	USEPA (1996)		
Linuron	350	ORNL (2006)	2.56E-07	ORNL (2006)			75	ORNL (2006)		
Malathion	31	ORNL (2006)	2.00E-07	ORNL (2006)			143	ORNL (2006)		
MCPA	29	ORNL (2006)	5.44E-08	ORNL (2006)			630	ORNL (2006)		
Methoxychlor	80,000	USEPA (1996)	0.000648	USEPA (1996)	1.56E-02	USEPA (1996)	0.045	USEPA (1996)		
Metolachlor	292	ORNL (2006)	3.68E-07	ORNL (2006)			530	ORNL (2006)		
Metribuzin	1,196	ORNL (2006)	4.78E-09	ORNL (2006)			1050	ORNL (2006)		
Paraquat (as dichloride)	1,405	ORNL (2006)	1.32E-11	ORNL (2006)			620000	ORNL (2006)		
Parathion	1,779	ORNL (2006)	1.22E-05	ORNL (2006)	1.70E-02	ORNL (2006)	11	ORNL (2006)		
Phorate	444	ORNL (2006)	0.000179	ORNL (2006)			50	ORNL (2006)		
Picloram	18	ORNL (2006)	2.18E-12	ORNL (2006)			430	ORNL (2006)		
Simazine	149	ORNL (2006)	3.85E-08	ORNL (2006)			6.2	ORNL (2006)		
Tebuthiron	23	ORNL (2006)	4.91E-09	ORNL (2006)			2500	ORNL (2006)		
Terbufos	979	ORNL (2006)	0.000981	ORNL (2006)			5.07	ORNL (2006)		
Toxaphene	95,816	USEPA (1996)	0.000246	USEPA (1996)	1.16E-02	USEPA (1996)	0.74	USEPA (1996)		
Triallate	1,641	ORNL (2006)	0.000789	ORNL (2006)			4	ORNL (2006)		
Trifluarin	9,682	ORNL (2006)	0.00421	ORNL (2006)	1.49E-02	ORNL (2006)	0.184	ORNL (2006)		
Other Organics										
Aniline	45	ORNL (2006)	8.26E-05	ORNL (2006)	7.00E-02	ORNL (2006)	36000	ORNL (2006)		
Bis(2-ethyl-hexyl)phthalate	111,123	USEPA (1996)	4.18E-06	USEPA (1996)	3.51E-02	USEPA (1996)	0.34	USEPA (1996)		
Bis(Chloro-methyl)ether	76	USEPA (1996)	0.000738	USEPA (1996)	6.92E-02	USEPA (1996)	0.000172	USEPA (1996)		
Dibutyl phthalate	1,460	ORNL (2006)	0.000074	ORNL (2006)	4.38E-02	ORNL (2006)	11.2	ORNL (2006)		
Dichlorobenzidine	7,489	ORNL (2006)	2.09E-09	ORNL (2006)	1.94E-02	ORNL (2006)	3.1	ORNL (2006)		

Table A-6. Chemical Parameters

	K_{oc} ml/g	Source	H' dimensionless	Source	D_a cm^2/s	Source	Solubility mg/L	Source	Half Life yr	Source
DIPA	*** 2.2	CCME (2006b)	7.00E-06	CCME (2006b)			870000	CCME (2006b)		
Ethylene glycol	0.0072	EC (1999b)	2.50E-06	EC (1999b)	0.108	ORNL (2006)	1000000	EC (1999b)		
Hexachlorobutadiene	994	ORNL (2006)	0.421	ORNL (2006)	5.61E-02	ORNL (2006)	3.2	ORNL (2006)		
Methylmethacrylate	10	ORNL (2006)	0.0138	ORNL (2006)	7.70E-02	ORNL (2006)	15000	ORNL (2006)		
MTBE	12	USEPA (1994)	0.023	USEPA (1994)	1.02E-01	ORNL (2006)	51000	USEPA (1994)		
Nonylphenol	141,254	EC (2002)	0.005	EC (2002)			5.43	EC (2002)		
Phenol	12	CCME (1999)	1.60E-05	CCME (1999)	0.082	ORNL (2006)	87,000	CCME (1999)		
Sulfolane	1.2	CCME (2006c)	3.60E-08	CCME (2006c)			1000000	CCME (2006c)		

Notes:

K_{oc} = organic carbon water partition coefficient

H' = dimensionless Henry's Law Coefficient

D_{air} = diffusion coefficient in air

na = not applicable or not available

****Value presented is a mean K_d, rather than a K_{oc} since DIPA sorbs to clays in preference to organic carbon.*

1. *Calculated using the equation $K_{oc} = 0.41xK_{ow}$*
2. *PCBs, diozins and furans are groups of chemicals with a wide range of chemical properties. Chemical properties are not provided for these groups.*

CCME (1999) refers to the Canadian Environmental Quality Guidelines (CEQG) and updates, including the scientific supporting documents that are summarized in the CEQG.

Table A-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	Source	Inhalation TC mg/m^3	Source	Oral SF $(mg/kg\text{-}d)^{-1}$	Source	Inhalation UR $(mg/m^3)^{-1}$	Source
Metals								
Arsenic (inorganic)					2.8	HC (2004b)	6.4	HC (2004b)
Barite-barium	0.07							
Hydrocarbons								
Benzene					0.31	HC (2004b)	0.0033	HC (2004b)
Toluene	0.22	HC (2004b)	3.8	HC (2004b)				
Ethylbenzene	0.1	US EPA (2006)	1.0	US EPA (2006)				
Xylenes	1.5	HC (2004b)	0.18	HC (2004b)				
Styrene	0.12	HC (2004b)	0.092	HC (2004b)				
Aliphatic C_6-C_8	5.0	CCME (2007a)	18.4	CCME (2007a)				
Aliphatic $C_{>8}$-C_{10}	0.1	CCME (2007a)	1.0	CCME (2007a)				
Aliphatic $C_{>10}$-C_{12}	0.1	CCME (2007a)	1.0	CCME (2007a)				
Aliphatic $C_{>12}$-C_{16}	0.1	CCME (2007a)	1.0	CCME (2007a)				
Aliphatic $C_{>16}$-C_{21}	2.0	CCME (2007a)		CCME (2007a)				
Aliphatic $C_{>21}$-C_{34}	2.0	CCME (2007a)		CCME (2007a)				
Aliphatic $C_{>34}$	20	CCME (2007a)		CCME (2007a)				
Aromatic $C_{>8}$-C_{10}	0.04	CCME (2007a)	0.2	CCME (2007a)				
Aromatic $C_{>10}$-C_{12}	0.04	CCME (2007a)	0.2	CCME (2007a)				
Aromatic $C_{>12}$-C_{16}	0.04	CCME (2007a)	0.2	CCME (2007a)				
Aromatic $C_{>16}$-C_{21}	0.03	CCME (2007a)		CCME (2007a)				
Aromatic $C_{>21}$-C_{34}	0.03	CCME (2007a)		CCME (2007a)				
Aromatic $C_{>34}$	0.03	CCME (2007a)		CCME (2007a)				
Naphthalene	0.02	US EPA (2006)	0.003	US EPA (2006)				
Acenaphthene	0.06	US EPA (2006)	0.27	see note 1				
Fluorene	0.04	US EPA (2006)	0.18	see note 1				
Fluoranthene	0.04	US EPA (2006)	0.18	see note 1				
Anthracene	0.3	US EPA (2006)	1.34	see note 1				
Pyrene	0.03	US EPA (2006)	0.13	see note 1				
Benzo(a)pyrene					2.3/25[2]	CCME (2007b)		
Halogenated Aliphatics								
Vinyl chloride	0.003	US EPA (2006)	0.1	US EPA (2006)	0.26	HC (2004b)	0.0088	US EPA (2006)

Table A-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	Source	Inhalation TC mg/m^3	Source	Oral SF $(mg/kg\text{-}d)^{-1}$	Source	Inhalation UR $(mg/m^3)^{-1}$	Source
1,1-Dichloroethene	0.05	HC (2004b)	0.2	US EPA (2006)				
Trichloroethene	0.00146	CCME (2006d)	0.04	CCME (2006d)	0.00025	CCME (2006d)	0.00061	CCME (2006d)
Tetrachloroethene	0.014	HC (2004b)	0.36	HC (2004b)				
1,2-Dichloroethane					0.00806	HC (2004b)	0.026	US EPA (2006)
Dichloromethane	0.05	HC (2004b)	3	ORNL (2006)	0.000079	HC (2004b)	0.000023	HC (2004b)
Trichloromethane	0.01	US EPA (2006)	0.04475	see note 1			0.023	US EPA (2006)
Tetrachloromethane	0.0007	US EPA (2006)	0.00313	see note 1	0.13	US EPA (2006)	0.015	US EPA (2006)
Dibromochloromethane	0.02	US EPA (2006)	0.08949	see note 1				
Chlorinated Aromatics								
Chlorobenzene	0.43	HC (2004b)	0.01	HC (2004b)				
1,2-Dichlorobenzene	0.43	HC (2004b)	1.92411	see note 1				
1,4-Dichlorobenzene	0.11	HC (2004b)	0.095	HC (2004b)				
1,2,3-Trichlorobenzene	0.0015	HC (2004b)	0.00671	see note 1				
1,2,4-Trichlorobenzene	0.0016	HC (2004b)	0.007	HC (2004b)				
1,3,5-Trichlorobenzene	0.0015	HC (2004b)	0.0036	HC (2004b)				
1,2,3,4-Tetrachlorobenzene	0.0034	HC (2004b)	0.01521	see note 1				
1,2,3,5-Tetrachlorobenzene	0.00041	HC (2004b)	0.00183	see note 1				
1,2,4,5-Tetrachlorobenzene	0.00021	HC (2004b)	0.00094	see note 1				
Pentachlorobenzene	0.001	HC (2004b)	0.00447	see note 1				
Hexachlorobenzene	0.0005	HC (2004b)	0.002237	see note 1	0.83	HC (2004b)	0.1855	see note 1
Dichlorophenol	0.1	HC (2004b)	0.447468	see note 1				
Trichlorophenol					0.02	HC (2004b)	0.0045	see note 1
Tetrachlorophenol	0.01	HC (2004b)	0.04475	see note 1				
Pentachlorophenol	0.006	HC (2004b)	0.02685	see note 1				
Dioxins and Furans	2.00E-09	HC (2004b)						
PCBs	0.001	HC (2004b)						
Pesticides								
Aldicarb	0.001	HC (2004b)						
Aldrin and dieldrin	0.0001	HC (2004b)						
Atrazine and metabolites	0.0005	HC (2004b)						
Azinphos-methyl	0.0025	HC (2004b)						

Table A-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	Source	Inhalation TC mg/m^3	Source	Oral SF (mg/kg-d)$^{-1}$	Source	Inhalation UR (mg/m^3)$^{-1}$	Source
Bendiocarb	0.004	HC (2004b)						
Bromoxynil	0.0005	HC (2004b)						
Carbaryl	0.01	HC (2004b)						
Carbofuran	0.01	HC (2004b)						
Chlorothalonil	0.015	US EPA (2006)						
Chlorpyrifos	0.01	HC (2004b)						
Cyanazine	0.0013	HC (2004b)						
2,4-D	0.01	HC (2004b)						
DDT	0.01	HC (2004b)						
Diazinon	0.002	HC (2004b)						
Dicamba	0.0125	HC (2004b)						
Dichlofop-methyl	0.001	HC (2004b)						
Dieldrin (see Aldrin and Dieldrin)								
Dimethoate	0.002	HC (2004b)						
Dinoseb	0.001	HC (2004b)						
Diquat	0.008	HC (2004b)						
Diuron	0.0156	HC (2004b)						
Endosulfan	6.00E-03	US EPA (2006)						
Endrin	3.00E-04	US EPA (2006)						
Glyphosate	0.03	HC (2004b)						
Heptachlor epoxide	1.30E-05	US EPA (2006)			9.1	US EPA (2006)	2.6	US EPA (2006)
Lindane	3.00E-04	US EPA (2006)						
Linuron	2.00E-03	US EPA (2006)						
Malathion	0.02	HC (2004b)						
MCPA	5.00E-04	US EPA (2006)						
Methoxychlor	0.1	HC (2004b)						
Metolachlor	0.005	HC (2004b)						
Metribuzin	0.0083	HC (2004b)						
Paraquat (as dichloride)	0.001	HC (2004b)						
Parathion	0.005	HC (2004b)						
Phorate	0.0002	HC (2004b)						
Picloram	0.02	HC (2004b)						

Table A-7. Human Toxicity Reference Values

	Non Carcinogenic TRV				Carcinogenic TRV			
	Oral TDI mg/kg-d	**Source**	**Inhalation TC mg/m^3**	**Source**	**Oral SF (mg/kg-d)$^{-1}$**	**Source**	**Inhalation UR (mg/m^3)$^{-1}$**	**Source**
Simazine	0.0013	HC (2004b)						
Tebuthiron	7.00E-02	US EPA (2006)						
Terbufos	0.00005	HC (2004b)						
Toxaphene					1.1	US EPA (2006)	0.32	US EPA (2006)
Triallate	1.30E-02	US EPA (2006)						
Trifluarin	0.0048	HC (2004b)						
Other Organics								
Aniline	0.007	HC (2004b)	0.0313	see note 1				
Bis(2-ethyl-hexyl)phthalate	0.044	HC (2004b)	0.1969	see note 1				
Bis(Chloro-methyl)ether					220	US EPA (2006)	4.93	HC (2004b)
Dibutyl phthalate	0.063	HC (2004b)	0.28191	see note 1				
Dichlorobenzidine					0.0676	HC (2004b)	0.015107214	see note 1
DIPA	0.39	CCME (2006b)						
Ethylene glycol	2	US EPA (2006)	8.94937	see note 1				
Hexachlorobutadiene					0.078	US EPA (2006)	0.022	US EPA (2006)
Methylmethacrylate	0.05	HC (2004b)	0.052	HC (2004b)				
MTBE	0.01	HC (2004b)	0.037	HC (2004b)				
Nonylphenol								
Phenol	0.06	HC (2004b)	0.26848	see note 1				
Sulfolane	0.0097	CCME (2006c)						

Notes:
TRV = toxicity reference value
TDI = tolerable daily intake
TC = tolerable concentration
SF = slope factor
UR = unit risk
1. estimated from the oral TDI assuming an adult body weight of 70.7 kg, and an inhalation rate of 15.8 m^3/d
2. slope factors for ingestion/inhalation and dermal contact respectively
CCME (1999) refers to the Canadian Environmental Quality Guidelines (CEQG) and updates, including the scientific supporting documents that are summarized in the CEQG.
HC = Health Canada

Table A-8. Human Absorption Factors

	Absorption Factors					
	Gut	**Source**	**Skin**	**Source**	**Lung**	**Source**
Metals						
Arsenic (inorganic)	1.00		0.03	HC (2004a)	1.00	
Barite-barium	1.00		1.00		1.00	
Hydrocarbons						
Benzene	1.00		0.08	HC (2004a)	1.00	
Toluene	1.00		0.12	HC (2004a)	1.00	
Ethylbenzene	1.00		0.20	HC (2004a)	1.00	
Xylenes	1.00		0.12	HC (2004a)	1.00	
Styrene	1.00		0.20	CCME (2007a)	1.00	
Aliphatic C_6-C_8	1.00		0.20	CCME (2007a)	1.00	
Aliphatic $C_{>8}$-C_{10}	1.00		0.20	CCME (2007a)	1.00	
Aliphatic $C_{>10}$-C_{12}	1.00		0.20	CCME (2007a)	1.00	
Aliphatic $C_{>12}$-C_{16}	1.00		0.20	CCME (2007a)	1.00	
Aliphatic $C_{>16}$-C_{21}	1.00		0.20	CCME (2007a)	1.00	
Aliphatic $C_{>21}$-C_{34}	1.00		0.20	CCME (2007a)	1.00	
Aliphatic $C_{>34}$	1.00		0.20	CCME (2007a)	1.00	
Aromatic $C_{>8}$-C_{10}	1.00		0.20	CCME (2007a)	1.00	
Aromatic $C_{>10}$-C_{12}	1.00		0.20	CCME (2007a)	1.00	
Aromatic $C_{>12}$-C_{16}	1.00		0.20	CCME (2007a)	1.00	
Aromatic $C_{>16}$-C_{21}	1.00		0.20	CCME (2007a)	1.00	
Aromatic $C_{>21}$-C_{34}	1.00		0.20	CCME (2007a)	1.00	
Aromatic $C_{>34}$	1.00		0.20	CCME (2007a)	1.00	
Naphthalene	1.00		0.10	CCME (1999)	1.00	
Acenaphthene	1.00		0.20	CCME (2007a)	1.00	
Fluorene	1.00		0.20	CCME (2007a)	1.00	
Fluoranthene	1.00		0.20	CCME (2007a)	1.00	
Anthracene	1.00		0.29	CCME (2007a)	1.00	
Pyrene	1.00		0.20	CCME (2007a)	1.00	
Benzo(a)pyrene	1.00		0.34	CCME (2007b)	1.00	
Halogenated Aliphatics						
Vinyl chloride	1.00		0.16	HC (2004a)	1.00	

Table A-8. Human Absorption Factors

	Absorption Factors					
	Gut	Source	Skin	Source	Lung	Source
1,1-Dichloroethene	1.00		0.10	HC (2004a)	1.00	
Trichloroethene	1.00		0.10	HC (2004a)	1.00	
Tetrachloroethene	1.00		0.10	HC (2004a)	1.00	
1,2-Dichloroethane	1.00		0.10	HC (2004a)	1.00	
Dichloromethane	1.00		1.00		1.00	
Trichloromethane	1.00		0.10	HC (2004a)	1.00	
Tetrachloromethane	1.00		0.10	HC (2004a)	1.00	
Dibromochloromethane	1.00		0.10	HC (2004a)	1.00	
Chlorinated Aromatics						
Chlorobenzene	1.00		0.10	HC (2004a)	1.00	
1,2-Dichlorobenzene	1.00		0.10	HC (2004a)	1.00	
1,4-Dichlorobenzene	1.00		0.10	HC (2004a)	1.00	
1,2,3-Trichlorobenzene	1.00		0.08	HC (2004a)	1.00	
1,2,4-Trichlorobenzene	1.00		0.08	HC (2004a)	1.00	
1,3,5-Trichlorobenzene	1.00		0.08	HC (2004a)	1.00	
1,2,3,4-Tetrachlorobenzene	1.00		1.00		1.00	
1,2,3,5-Tetrachlorobenzene	1.00		1.00		1.00	
1,2,4,5-Tetrachlorobenzene	1.00		1.00		1.00	
Pentachlorobenzene	1.00		1.00		1.00	
Hexachlorobenzene	1.00		0.13	HC (2004a)	1.00	
Dichlorophenol	1.00		1.00		1.00	
Trichlorophenol	1.00		1.00		1.00	
Tetrachlorophenol	1.00		1.00		1.00	
Pentachlorophenol	1.00		0.11	HC (2004a)	1.00	
Dioxins and Furans	1.00		1.00		1.00	
PCBs	1.00		1.00		1.00	
Pesticides						
Aldicarb	1.00		1.00		1.00	
Aldrin and dieldrin	1.00		0.25	HC (2004a)	1.00	
Atrazine and metabolites	1.00		1.00		1.00	
Azniphos-methyl	1.00		1.00		1.00	

Table A-8. Human Absorption Factors

	Absorption Factors					
	Gut	Source	Skin	Source	Lung	Source
Bendiocarb	1.00		1.00		1.00	
Bromoxynil	1.00		1.00		1.00	
Carbaryl	1.00		1.00		1.00	
Carbofuran	1.00		1.00		1.00	
Chlorothalonil	1.00		1.00		1.00	
Chlorpyrifos	1.00		1.00		1.00	
Cyanazine	1.00		1.00		1.00	
2,4-D	1.00		1.00		1.00	
DDT	1.00		1.00		1.00	
Diazinon	1.00		1.00		1.00	
Dicamba	1.00		1.00		1.00	
Dichlofop-methyl	1.00		1.00		1.00	
Dieldrin (see Aldrin and Dieldrin)	1.00		1.00		1.00	
Dimethoate	1.00		1.00		1.00	
Dinoseb	1.00		1.00		1.00	
Diquat	1.00		1.00		1.00	
Diuron	1.00		1.00		1.00	
Endosulfan	1.00		0.20	HC (2004a)	1.00	
Endrin	1.00		0.25	HC (2004a)	1.00	
Glyphosate	1.00		1.00		1.00	
Heptachlor epoxide	1.00		0.20	HC (2004a)	1.00	
Lindane	1.00		1.00		1.00	
Linuron	1.00		1.00		1.00	
Malathion	1.00		1.00		1.00	
MCPA	1.00		1.00		1.00	
Methoxychlor	1.00		0.20	HC (2004a)	1.00	
Metolachlor	1.00		1.00		1.00	
Metribuzin	1.00		1.00		1.00	
Paraquat (as dichloride)	1.00		1.00		1.00	
Parathion	1.00		1.00		1.00	
Phorate	1.00		1.00		1.00	

Table A-8. Human Absorption Factors

	Absorption Factors					
	Gut	**Source**	**Skin**	**Source**	**Lung**	**Source**
Picloram	1.00		1.00		1.00	
Simazine	1.00		1.00		1.00	
Tebuthiron	1.00		1.00		1.00	
Terbufos	1.00		1.00		1.00	
Toxaphene	1.00		1.00		1.00	
Triallate	1.00		1.00		1.00	
Trifluarin	1.00		1.00		1.00	
Other Organics						
Aniline	1.00		1.00		1.00	
Bis(2-ethyl-hexyl)phthalate	1.00		0.02	HC (2004a)	1.00	
Bis(Chloro-methyl)ether	1.00		1.00		1.00	
Dibutyl phthalate	1.00		1.00		1.00	
Dichlorobenzidine	1.00		0.54	HC (2004a)	1.00	
DIPA	1.00		1.00		1.00	
Ethylene glycol	1.00		1.00		1.00	
Hexachlorobutadiene	1.00		0.20	HC (2004a)	1.00	
Methylmethacrylate	1.00		1.00		1.00	
MTBE	1.00		0.10	HC (2004a)	1.00	
Nitriloacetic acid	1.00		1.00		1.00	
Nonylphenol	1.00		1.00		1.00	
Phenol	1.00		0.26	HC (2004a)	1.00	
Sulfolane	1.00		1.00		1.00	
Trihalomethanes - total (THMs)	1.00		1.00		1.00	

Notes:

Sources only provided where an absorption factor other than 1.0 is used.

CCME (1999) refers to the Canadian Environmental Quality Guidelines (CEQG) and updates, including the scientific supporting documents that are summarized in the CEQG.

HC = Health Canada

Table A-9. Human Background Exposure Parameters

	Toddler EDI mg/kg-d	Adult EDI mg/kg-d	Source	C_a mg/m^3	Source	BSC mg/kg	Source	SAF
Metals								
Arsenic (inorganic)	na	na	CCME (1999)	na	CCME (1999)	10	CCME (1999)	0.2
Barite-barium	0.014	0.014	AENV 2004	na	AENV 2004	325	AENV 2004	0.25
Hydrocarbons								
Benzene	na	na	-	na	-	0	assumed	na
Toluene	0.0028	0.0028	EC (2004b)	0.0442	EC (2004b)	0	assumed	0.5
Ethylbenzene	0.0029	0.0029	EC (2004b)	0.0075	EC (2004b)	0	assumed	0.5
Xylenes	0.0079	0.0079	EC (2004b)	0.00182	EC (2004b)	0	assumed	0.5
Styrene	0.00071	0.00027	PSL	0.00028	PSL	0	assumed	0.5
Aliphatic C_6-C_8	0.02334	0.02334	CCME (2007a)	0.09111	CCME (2007a)	0	assumed	0.5
Aliphatic $C_{>8}$-C_{10}	0.0103	0.0103	CCME (2007a)	0.03881	CCME (2007a)	0	assumed	0.5
Aliphatic $C_{>10}$-C_{12}	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.5
Aliphatic $C_{>12}$-C_{16}	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.5
Aliphatic $C_{>16}$-C_{21}	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.6
Aliphatic $C_{>21}$-C_{34}	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.6
Aliphatic $C_{>34}$	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.8
Aromatic $C_{>8}$-C_{10}	0.00938	0.00938	CCME (2007a)	0.03745	CCME (2007a)	0	assumed	0.5
Aromatic $C_{>10}$-C_{12}	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.5
Aromatic $C_{>12}$-C_{16}	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.5
Aromatic $C_{>16}$-C_{21}	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.6
Aromatic $C_{>21}$-C_{34}	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.6
Aromatic $C_{>34}$	0	0	CCME (2007a)	0	CCME (2007a)	0	assumed	0.8
Naphthalene	0.00053545	0.00021231	ATSDR (2005)	0.00095	ATSDR (2005)	0	assumed	0.5
Acenaphthene	0	0	assumed	0	assumed	0	assumed	0.5
Fluorene	0.00902	0.00358	ATSDR (1995)	0.016	ATSDR (1995)	0	assumed	0.5
Fluoranthene	0	0	assumed	0	assumed	0	assumed	0.5
Anthracene	0.00502	0.00199	ATSDR (1995)	0.0089	ATSDR (1995)	0	assumed	0.5
Pyrene	0.00620	0.00246	ATSDR (1995)	0.011	ATSDR (1995)	0	assumed	0.5
Benzo(a)pyrene	na	na	-	na	-	0.07	CCME (2007b)	na

Table A-9. Human Background Exposure Parameters

	Toddler EDI mg/kg-d	Adult EDI mg/kg-d	Source	C_a mg/m^3	Source	BSC mg/kg	Source	SAF
Halogenated Aliphatics								
Vinyl chloride	0	0	assumed	0	assumed	0	assumed	0.2
1,1-Dichloroethene	0	0	assumed	0	assumed	0	assumed	0.2
Trichloroethene	0.00053	0.00041	CCME (2006d)	0.0014	CCME (2006d)	0	assumed	0.2
Tetrachloroethene	0	0	assumed	0	assumed	0	assumed	0.2
1,2-Dichloroethane	0.0006	0.0005	PSL	0.0018	PSL	0	assumed	0.2
Dichloromethane	0.00558	0.00471	PSL	0.0063	PSL	0	assumed	0.2
Trichloromethane	0.004315	0.00361	PSL	0.0063	PSL	0	assumed	0.2
Tetrachloromethane	0	0	assumed	0	assumed	0	assumed	0.2
Dibromochloromethane	0	0	assumed	0	assumed	0	assumed	0.2
Chlorinated Aromatics								
Chlorobenzene	0.000122	0.000066	PSL	0.00016	PSL	0	assumed	0.2
1,2-Dichlorobenzene	0.00004	0.00003	PSL	0.1	PSL	0	assumed	0.2
1,4-Dichlorobenzene	0.0014	0.0009	PSL	0.0028	PSL	0	assumed	0.2
1,2,3-Trichlorobenzene	0.00023	0.00024	PSL	0.0008	PSL	0	assumed	0.2
1,2,4-Trichlorobenzene	0.0006	0.00045	PSL	0.0018	PSL	0	assumed	0.2
1,3,5-Trichlorobenzene	0.00032	0.00025	PSL	0.0008	PSL	0	assumed	0.2
1,2,3,4-Tetrachlorobenzene	0.0000007	0.00000025	PSL	0.00000017	PSL	0	assumed	0.2
1,2,3,5-Tetrachlorobenzene	0.00000045	0.00000015	PSL	0.00000017	PSL	0	assumed	0.2
1,2,4,5-Tetrachlorobenzene	0.0000007	0.0000002	PSL	0.00000017	PSL	0	assumed	0.2
Pentachlorobenzene	0.000002	0.0000005	PSL	0.0000001	PSL	0	assumed	0.2
Hexachlorobenzene	0.0000178	0.0000028	PSL	0.00000015	PSL	0	assumed	0.2
2,4-Dichlorophenol	0	0	assumed	0	assumed	0	assumed	0.2
2,4,6-Trichlorophenol	0	0	assumed	0	assumed	0	assumed	0.2
2,3,4,6-Tetrachlorophenol	0	0	assumed	0	assumed	0	assumed	0.2
Pentachlorophenol	0	0	assumed	0	assumed	0	assumed	0.2
Dioxins and Furans	7.1E-09	1.33E-09	EC (2000)	0	assumed	0	assumed	0.25
PCBs	7.6925E-06	0.00000254	EC (2001)	0	assumed	0	assumed	0.2

Table A-9. Human Background Exposure Parameters

	Toddler EDI mg/kg-d	Adult EDI mg/kg-d	Source	C_a mg/m^3	Source	BSC mg/kg	Source	SAF
Pesticides								
Aldicarb	0	0	assumed	0	assumed	0	assumed	0.2
Aldrin and dieldrin	0	0	assumed	0	assumed	0	assumed	0.2
Atrazine and metabolites	0	0	assumed	0	assumed	0	assumed	0.2
Azinphos-methyl	0	0	assumed	0	assumed	0	assumed	0.2
Bendiocarb	0	0	assumed	0	assumed	0	assumed	0.2
Bromoxynil	0	0	assumed	0	assumed	0	assumed	0.2
Carbaryl	0	0	assumed	0	assumed	0	assumed	0.2
Carbofuran	0	0	assumed	0	assumed	0	assumed	0.2
Chlorothalonil	0	0	assumed	0	assumed	0	assumed	0.2
Chlorpyrifos	0	0	assumed	0	assumed	0	assumed	0.2
Cyanazine	0	0	assumed	0	assumed	0	assumed	0.2
2,4-D	0	0	assumed	0	assumed	0	assumed	0.2
DDT	0	0	assumed	0	assumed	0	assumed	0.2
Diazinon	0	0	assumed	0	assumed	0	assumed	0.2
Dicamba	0	0	assumed	0	assumed	0	assumed	0.2
Dichlofop-methyl	0	0	assumed	0	assumed	0	assumed	0.2
Dieldrin (see Aldrin and Dieldrin)								
Dimethoate	0	0	assumed	0	assumed	0	assumed	0.2
Dinoseb	0	0	assumed	0	assumed	0	assumed	0.2
Diquat	0	0	assumed	0	assumed	0	assumed	0.2
Diuron	0	0	assumed	0	assumed	0	assumed	0.2
Endosulfan	0	0	assumed	0	assumed	0	assumed	0.2
Endrin	0	0	assumed	0	assumed	0	assumed	0.2
Glyphosate	0	0	assumed	0	assumed	0	assumed	0.2
Heptachlor epoxide	0	0	assumed	0	assumed	0	assumed	0.2
Lindane	0	0	assumed	0	assumed	0	assumed	0.2
Linuron	0	0	assumed	0	assumed	0	assumed	0.2
Malathion	0	0	assumed	0	assumed	0	assumed	0.2

Table A-9. Human Background Exposure Parameters

	Toddler EDI mg/kg-d	Adult EDI mg/kg-d	Source	C_a mg/m^3	Source	BSC mg/kg	Source	SAF
MCPA	0	0	assumed	0	assumed	0	assumed	0.2
Methoxychlor	0	0	assumed	0	assumed	0	assumed	0.2
Metolachlor	0	0	assumed	0	assumed	0	assumed	0.2
Metribuzin	0	0	assumed	0	assumed	0	assumed	0.2
Paraquat (as dichloride)	0	0	assumed	0	assumed	0	assumed	0.2
Parathion	0	0	assumed	0	assumed	0	assumed	0.2
Phorate	0	0	assumed	0	assumed	0	assumed	0.2
Picloram	0	0	assumed	0	assumed	0	assumed	0.2
Simazine	0	0	assumed	0	assumed	0	assumed	0.2
Tebuthiron	0	0	assumed	0	assumed	0	assumed	0.2
Terbufos	0	0	assumed	0	assumed	0	assumed	0.2
Toxaphene	0	0	assumed	0	assumed	0	assumed	0.2
Triallate	0	0	assumed	0	assumed	0	assumed	0.2
Trifluarin	0	0	assumed	0	assumed	0	assumed	0.2
Other Organics								
Aniline	0	0	assumed	0	assumed	0	assumed	0.2
Bis(2-ethyl-hexyl)phthalate	0.01892	0.0058	PSL	0.031	PSL	0	assumed	0.2
Bis(Chloro-methyl)ether	0	0	assumed	0	assumed	0	assumed	0.2
Dibutyl phthalate	0.005	0.0019	PSL	0.00285	PSL	0	assumed	0.2
Dichlorobenzidine	0	0	assumed	0	assumed	0	assumed	0.2
DIPA	0	0	assumed	0	assumed	0	assumed	0.33
Ethylene glycol	0.0344	0.0167	PSL	0	PSL	0	assumed	0.33
Hexachlorobutadiene	0.00012	0.00003	PSL	0.00006	PSL	0	assumed	0.2
Methylmethacrylate	1.13E-07	0	PSL	2.44E-07	PSL	0	assumed	0.2
MTBE	0.00000067	0.0000005	PSL	0.0000015	PSL	0	assumed	0.2
Nonylphenol	na	na	-	na	-	0	assumed	na
Phenol	0	0	assumed	0	assumed	0	assumed	0.2
Sulfolane	0	0	assumed	0	assumed	0	assumed	0.5

Table A-9. Human Background Exposure Parameters

Notes:
na = not available or not applicable
EDI = estimated daily intake
C_a *= background indoor air concentration*
SAF = soil allocation factor
PSL = Priority Substance List assessment under Canadian Environmental Protection Act (CEPA) for corresponding substance.
CCME (1999) refers to the Canadian Environmental Quality Guidelines (CEQG) and updates, including the scientific supporting documents that are summarized in the CEQG.

Table A-10. Petroleum Hydrocarbon Subfraction Distribution

Soil				
	TPH Sub-fraction (Proportion of Total Fraction Mass)			
Fraction	**Fraction 1**	**Fraction 2**	**Fraction 3**	**Fraction 4**
Aliphatics				
C6-C8	0.55			
C>8-C10	0.36			
C>10-C12		0.36		
C>12-C16		0.44		
C>16-C21			0.56	
C>21-C34			0.24	
C>34				0.8
Aromatics				
C>7-C8				
C>8-C10	0.09			
C>10-C12		0.09		
C>12-C16		0.11		
C>16-C21			0.14	
C>21-C34			0.06	
C>34				0.2
Sum of all subfractions	1	1	1	1

Notes:
Source: CCME (2007a)

Groundwater				
	TPH Sub-fraction (Proportion of Total Fraction Mass)			
	Fine Soil		**Coarse Soil**	
Fraction	**Fraction 1**	**Fraction 2**	**Fraction 1**	**Fraction 2**
Aliphatics				
C6-C8	0.5768		0.6047	
C>8-C10	0.0663		0.0632	
C>10-C12		0.0239		0.024
C>12-C16		0.0015		0.0015
Aromatics				
C>7-C8				
C>8-C10	0.3569		0.3321	
C>10-C12		0.6029		0.6034
C>12-C16		0.3718		0.3711
Sum of all subfractions	1	1	1	1

Notes:
Source: CCME (2007a)
Subfraction distribution in groundwater not required for F3 and F4 due to low aqueous solubility
These values were calculated from the soil subfraction distributions above
based on equilibrium partitioning assumptions, see text.

Table A-11. Surface Water Quality Guidelines

	Drinking Water (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED[1] (mg/kg-bw/d)
General and Inorganic Parameters						
Total Dissolved Solids (TDS)			500	3000		
Metals						
Arsenic (inorganic)	0.025	0.005	0.1	0.025		
Barium	1					
Boron	5		0.5	5.0		
Cadmium	0.005	see note 3	0.0051	0.11		
Chloride	250	230	100			
Chromium (total)	0.05	see note 3	0.0049	0.05		
Copper	1	see note 3	0.2	0.5		
Fluoride	1.5		1	1		
Iron	0.3	0.3	5			
Lead	0.01	see note 3	0.2	0.1		
Manganese	0.05		0.2			
Mercury	0.001	see note 3		0.003		
Nickel		see note 3	0.2	1		
Selenium	0.01	0.001	0.02	0.05		
Silver		see note 3	0.02	0.05		
Sulphate	500			1000		
Uranium	0.02		0.01	0.2		
Zinc	5	0.03	1	50		
Hydrocarbons						
Benzene	0.005	0.37		0.088	0.076	0.08
Toluene	0.024	0.002		4.91	4.25	4.46
Ethylbenzene	0.0024	0.09		3.20	2.77	2.91
Xylenes	0.3	0.18		13.1	11.3	11.9
Styrene	2.828	0.072				
Aliphatic C_6-C_8	136.85815	0.0465		53.6	46.4	48.72
Aliphatic $C_{>8}$-C_{10}	2.46675	0.0076		53.6	46.4	48.72
Aromatic $C_{>8}$-C_{10}	0.84205	0.14		53.6	46.4	48.72
F1				53.6	46.4	48.72
Aliphatic $C_{>10}$-C_{12}	2.75	0.00118		49.2	42.6	44.73
Aliphatic $C_{>12}$-C_{16}	2.75	0.000074		49.2	42.6	44.73
Aromatic $C_{>10}$-C_{12}	1.1	0.096		49.2	42.6	44.73

Table A-11. Surface Water Quality Guidelines

	Drinking Water (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED[1] (mg/kg-bw/d)
Aromatic $C_{>12}$-C_{16}	1.1	0.0554		49.2	42.6	44.73
F2				49.2	42.6	44.73
F3				79.7	69.0	72.45
F4				42.0	36.4	38.22
Acenapthene	1.414	0.0058		1.9	1.7	0.35
Acenaphthylene[2]		0.046				
Anthracene	7.07	0.000012		13.4	11.9	20
Fluoranthene	0.942666667	0.00004		1.4	1.2	0.25
Fluorene	0.942666667	0.003		1.4	1.2	0.25
Naphthalene	0.471333333	0.0011		0.88	0.76	0.16
Phenanthrene		0.0004		3.9	3.3	0.7
Pyrene	0.707	0.000025		13.4	11.9	1.5
Benz[a]anthracene		0.000018		8.3	7.1	1.5
Benzo[b+j]fluoranthene				0.55	0.48	0.1
Benzo[k]fluoranthene				0.55	0.48	0.1
Benzo[g,h,i]perylene						
Benzo[a]pyrene	0.00001	0.000015		0.72	0.62	0.13
Chrysene				0.55	0.48	0.1
Dibenz[a,h]anthracene				0.26	0.23	0.048
Indeno[1,2,3-c,d]pyrene						
Halogenated Aliphatics						
Vinyl chloride	0.002					
1,1-Dichloroethene	0.014					
Trichloroethene	0.005	0.021		0.05		
Tetrachloroethene	0.03	0.111				
1,2-Dichloroethane	0.005	0.1		0.005		
Dichloromethane	0.05	0.0981		0.05		
Trichloromethane	0.117833333	0.0018		0.1		
Tetrachloromethane	0.005	0.0133		0.005		
Tribromonethane				0.1		
Dibromochloromethane	0.188533333			0.1		
Chlorinated Aromatics						
Chlorobenzene	0.03	0.0013				
1,2-Dichlorobenzene	0.003	0.0007				

Table A-11. Surface Water Quality Guidelines

	Drinking Water (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED[1] (mg/kg-bw/d)
1,3-Dichlorobenzene		0.15				
1,4-Dichlorobenzene	0.001	0.026				
1,2,3-Trichlorobenzene	0.017675	0.008				
1,2,4-Trichlorobenzene	0.018853333	0.024				
1,3,5-Trichlorobenzene	0.017675					
1,2,3,4-Tetrachlorobenzene	0.040063333	0.0018				
1,2,3,5-Tetrachlorobenzene	0.004831167					
1,2,4,5-Tetrachlorobenzene	0.0024745					
Pentachlorobenzene	0.011783333	0.006				
Hexachlorobenzene	0.000568			0.00052		
2,4-Dichlorophenol	0.0003	0.0002				
2,4,6-Trichlorophenol	0.002	0.018				
2,3,4,6-Tetrachlorophenol	0.001	0.001				
Pentachlorophenol	0.03	0.0005				
Dioxins and Furans	1.17833E-07					
PCBs	0.009426667					
Pesticides						
Aldicarb	0.009	0.001	0.0549	0.011		
Aldrin	0.0007	0.003				
Atrazine and metabolites	0.004713333	0.0018	0.01	0.005		
Azinphos-methyl	0.02	0.00001				
Bendiocarb	0.04					
Bromoxynil	0.005	0.005	0.00033	0.011		
Carbaryl	0.09	0.0002		1.1		
Carbofuran	0.09	0.0018		0.045		
Chlorothalonil	0.1414	0.00018	0.0058	0.17		
Chlorpyrifos	0.09	0.0000035		0.024		
Cyanazine	0.01	0.002	0.0005	0.01		
2,4-D	0.1	0.004		0.1		
DDT	0.471333333	0.000001				
Diazinon	0.02					
Dicamba	0.12	0.01	0.000006	0.122		
Dichlofop-methyl	0.009	0.0061	0.00018	0.009		
Dieldrin	0.0007	0.000056				

Table A-11. Surface Water Quality Guidelines

	Drinking Water (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED [1] (mg/kg-bw/d)
Dimethoate	0.02	0.0062		0.003		
Dinoseb	0.01	0.00005	0.016	0.15		
Diquat	0.07					
Diuron	0.15					
Endosulfan	0.05656	0.00002				
Endrin	0.002828	0.000036				
Glyphosate	0.28	0.065		0.28		
Heptachlor epoxide	5.17949E-05	0.0000038				
Lindane	0.002828	0.00001		0.004		
Linuron	0.018853333	0.007	0.000071			
Malathion	0.19	0.0001				
MCPA	0.004713333	0.0026	0.000025	0.025		
Methoxychlor	0.9	0.00003				
Metolachlor	0.05	0.0078	0.028	0.05		
Metribuzin	0.08	0.001	0.0005	0.08		
Paraquat (as dichloride)	0.01					
Parathion	0.05	0.000013				
Phorate	0.002					
Picloram	0.19	0.029		0.19		
Simazine	0.01	0.01	0.0005	0.01		
Tebuthiron	0.659866667	0.0016	0.00027	0.13		
Terbufos	0.001					
Toxaphene	0.000428485	0.0000002				
Triallate	0.122546667	0.00024		0.23		
Trifluarin	0.045	0.0002		0.045		
Other Organics						
Aniline	0.065986667	0.0022				
Bis(2-ethyl-hexyl)phthalate	0.518466667	0.016				
Bis(Chloro-methyl)ether	2.14242E-06					
Dibutyl phthalate	0.74235	0.019				
Dichlorobenzidine	0.006972387					
DIPA	37	1.6	5	0.002		6.1
Ethylene glycol	31.42222222	192				
Hexachlorobutadiene	0.006042735	0.0013				

Table A-11. Surface Water Quality Guidelines

	Drinking Water (mg/L)	Aquatic Life (mg/L)	Irrigation (mg/L)	Livestock Water (mg/L)	Wildlife Water (mg/L)	DTED[1] (mg/kg-bw/d)
Methylmethacrylate	0.589166667					
MTBE	0.117833333	10				
Nitriloacetic acid	0.4					
Nonylphenol		0.001				
Phenol	0.5656	0.004		0.002		
Sulfolane	0.46	50	2	2.42	2.10	2.2
Trihalomethanes - total (THMs)	0.1					

Notes:
See text for guideline sources
1. *DTED = daily threshold effect dose from CCME (1999). Included where used to calculate livestock and wildlife watering guidelines*
2. *Aquatic life guideline from CCME (2007b)*
3. *See Surface Water Quality Guidelines for Use in Alberta (AENV, 1999)*

APPENDIX B INFLUENCE OF PARAMETERS ON GUIDELINE VALUES FOR VARIOUS EXPOSURE PATHWAYS

The key model parameters that affect Tier 2 objectives are highly dependent on the governing pathway. The following section highlights the key Tier 2 adjustable model parameters affecting each of the exposure pathways. A summary of the influence of key parameters is presented in Table B-1. Further considerations for individual model parameters, including measurement methods/locations, are discussed in Appendix C. The proponent is obligated to consider all site characteristics at Tier 2, and not just those which would result in higher Tier 2 objectives, and that several groups of parameters must always be measured together, as discussed in Appendix C.

Tier 2 Soil Objectives

Human Direct Contact (soil ingestion, dermal contact and particulate inhalation)

Guidelines for the human direct soil contact pathway cannot normally be adjusted at Tier 2 since they are affected only by the exposure scenario, receptor characteristics and chemical properties, none of which can be modified for Tier 2 closure.

Vapour Inhalation

Key parameters affecting vapour inhalation include the soil vapour permeability, soil organic carbon content, soil moisture content and depth to contamination. Increasing soil vapour permeability leads to lower Tier 2 objectives; higher values for the other three parameters lead to higher Tier 2 objectives. Soil bulk density has a moderate effect as well, with higher bulk density (and therefore lower total soil porosity) generally leading to higher Tier 2 objectives.

Of particular concern for the vapour inhalation pathway are very permeable soils such as well-sorted gravels beneath buildings, or buildings without concrete foundation slabs. If either of these situations occurs, the Tier 1 objectives may not be protective and a Tier 2 assessment is required.

Soil moisture may be difficult to modify based on the need to assess temporal variability in moisture content as well as spatial variability. This often leads to need for in situ monitoring requirements. See appendix C for further details.

Protection of Potable Water and Livestock/Irrigation Water

The protection of potable water and livestock/irrigation watering are all based on the protection of an aquifer assumed to be in contact with the contamination at Tier 1. These pathways are strongly affected by the soil organic carbon fraction, with a higher organic carbon resulting in higher Tier 2 objectives. The presence of vertical separation between the contamination and the groundwater aquifer also results in higher Tier 2 objectives. The saturated hydraulic conductivity and hydraulic gradient have a moderate effect on this pathway, with higher values of these parameters resulting in higher Tier 2 objectives. The source length (parallel to the direction of groundwater flow) has a moderate effect, with larger sources resulting in lower Tier 2 objectives. Soil bulk density has a smaller effect on these pathways, with higher bulk density resulting in lower Tier 2 levels in the

absence of an offset distance. For scenarios with a lateral offset between the source and receptor, parameter influences are as for the aquatic life and wildlife watering pathways (below). In the case of a Domestic Use Aquifer, a lateral offset between the contamination and existing water user cannot be applied at Tier 2 (the entire aquifer is considered to be the point of compliance). See Appendix E for a description of a Domestic Use Aquifer.

The Tier 1 objectives may not be protective of soils with low organic carbon content, such as well sorted gravels, and a Tier 2 assessment is required in these cases. Source areas that are significantly larger than the default values also require a Tier 2 assessment or site-specific risk assessment.

Protection of Groundwater for Aquatic Life and Wildlife Watering

The protection of groundwater for aquatic life and for wildlife watering differ from the other groundwater pathways due to the presence of an assumed offset to a fixed surface water body. The effect of the organic carbon fraction is similar to the other groundwater pathways. Saturated hydraulic conductivity and hydraulic gradient have a very strong effect on these pathways, with higher values for these parameters resulting in lower Tier 2 objectives. The distance to the surface water body also has a large effect for contaminants that are known to biodegrade in the subsurface, with greater distances resulting in larger Tier 2 objectives. Increased source length (parallel to groundwater flow) results in lower Tier 2 objectives; increasing soil bulk density results in slightly higher Tier 2 objectives.

The Tier 1 objectives may not be protective of soils with low organic carbon content or high saturated hydraulic conductivity such as well sorted gravels or high hydraulic gradients, and a Tier 2 assessment is required in these cases. Sources that are significantly larger than the default scenario also require a Tier 2 assessment.

Ingestion of Produce, Meat and Dairy

The ingestion of produce, meat and dairy by humans cannot be adjusted at Tier 2 at this time.

Ecological Soil Contact

The ecological soil contact pathway cannot normally be adjusted. For a select number of compounds, it may be possible to evaluate ecological soil contact at Tier 2 Site Specific Risk Assessment.

Livestock/Wildlife Soil and Food Ingestion

The livestock and wildlife soil and food ingestion pathways cannot be adjusted in the model at this time.

Offsite Migration

The offsite migration pathway cannot be adjusted at Tier 2. However, it only applies if there are more sensitive properties in the vicinity of the site and rarely governs.

Management Levels

Management levels, when specified, cannot be adjusted or excluded.

Tier 2 Groundwater Objectives

Vapour Inhalation

The vapour inhalation pathway is strongly affected by the soil vapour permeability, with higher vapour permeability resulting in lower Tier 2 objectives. The depth to groundwater can also have a significant effect, with a greater depth to groundwater resulting in higher Tier 2 objectives. Shallow groundwater in contact with a building or where high water table conditions or the capillary fringe may lead to contact with the building leads to a requirement for a site-specific risk assessment. Alternatively, it is permissible to use a risk-based value in these cases based on a 0.01 attenuation coefficient (dilution factor of 100), rather than a calculated dilution factor for the building similar to cases where contamination is within 30 cm of the building (see section C.7).

Higher soil bulk density and soil moisture content also lead to higher Tier 2 objectives.

As for soil guidelines for this pathway, the presence of high permeability soils or buildings without concrete foundations requires a Tier 2 assessment. Presence or potential presence of receptors that are more sensitive than the standard land use definition generally requires a Tier 2 re-evaluation but often can be dealt with by choosing a more sensitive land use definition at Tier 1 where those receptors are allowed.

Potable Water and Livestock/Irrigation Water

Groundwater objectives for the protection of potable water, livestock water and irrigation water cannot normally be adjusted at Tier 2, since the point of compliance is the entire aquifer for these pathways. However, it may be appropriate to apply the livestock and irrigation water pathways with an offset distance at Tier 2 if the subject site is not agricultural but there are agricultural properties downgradient – in this case the guidelines for these pathways are calculated in a similar manner to the aquatic life and wildlife watering pathways (below).

Aquatic Life and Wildlife Watering

The aquatic life and wildlife watering pathways are strongly affected by the distance to the surface water body, saturated hydraulic conductivity and hydraulic gradient. Increasing the distance to surface water results in higher Tier 2 objectives for chemicals where a saturated zone degradation rate is specified. Increasing the hydraulic conductivity and hydraulic gradient results in lower Tier 2 objectives. The organic carbon content in the saturated zone affects this pathway if the contaminant biodegrades in the subsurface; in this case higher organic carbon content results in higher Tier 2 objectives. The soil dry bulk density also influences these pathways; a higher bulk density (and therefore a lower soil porosity) results in higher Tier 2 objectives.

Management Limits

Management limits, when specified, cannot be modified or eliminated at Tier 2.

Chemical-Specific Considerations

In some cases model parameters may have a greater or lesser influence on particular groups of chemicals. For pathways involving lateral groundwater transport, the model is relatively insensitive to changes where biodegradation is not allowed. Biodegradation rates are provided in Table A-6 for certain chemicals considered to have sufficient data available. Tier 1 guidelines have been established for other substances that may also biodegrade, but where AENV has not specified biodegradation rates. Incorporation of a biodegradation component into the Tier 2 model for these substances is not permitted. It may be possible to use a site-specific approach in these instances that incorporates a combination of long term monitoring and modeling to determine risk to receptors with adequate supporting data from the site.

TABLE B.1
INFLUENCE OF TIER 2 ADJUSTABLE AND MEASURABLE PARAMETERS ON SOIL OBJECTIVES

Tier 2 Objective Type	Exposure Pathway or Receptor	PARAMETER: Soil Vapour Permeability	Soil Moisture Content	Soil Bulk Density	Organic Carbon Fraction	Hydraulic Conductivity	Hydraulic Gradient	Source Length	Depth to Contamination[a]	Depth to Groundwater[b]	Distance to Receptors[c]	Additional Comments
Soil Objectives	Direct Contact	-	-	-	-	-	-	-	-	-	-	d
	Vapour inhalation	↓↓	↑↓	↑↓	↑↑	-	-	-	↑↑	-	-	
	Potable Water	-	↑↓	↑↓	↑↑	↑[e]	↑[e]	↓	-	-	↑↑[f]	
	Livestock watering	-	↑↓	↑↓	↑↑	↑[e]	↑[e]	↓	-	-	↑↑[f]	
	Aquatic life	-	↑↓	↑↓	↑↑	↓↓[f]	↓↓[f]	↓	-	-	↑↑[f]	
	Wildlife watering	-	↑↓	↑↓	↑↑	↓↓[f]	↓↓[f]	↓	-	-	↑↑[f]	
	Eco Soil Ingestion	-	-	-	-	-	-	-	-	-	-	d
	Eco Soil Contact	-	-	-	-	-	-	-	-	-	-	d
	Offsite Migration	-	-	-	-	-	-	-	-	-	-	d
	Management Level	-	-	-	-	-	-	-	-	-	-	d
Groundwater Objectives	Vapour inhalation	↓↓	↑	↑	-	-	-	-	-	↑↑	-	
	Potable Water	-	-	-	-	-	-	-	-	-	↑↑[f]	
	Livestock watering	-	-	-	-	-	-	-	-	-	↑↑[f]	
	Aquatic life[e]	-	-	↑	-	↓↓[f]	↓↓[f]	-	-	-	↑↑[f]	
	Wildlife watering[e]	-	-	↑	-	↓↓[f]	↓↓[f]	-	-	-	↑↑[f]	
	Management Level[d]	-	-	-	-	-	-	-	-	-	-	d

↑↑ strongly influential; increasing the parameter increases the Tier 2 guideline
↑ somewhat influential; increasing the parameter increases the Tier 2 guideline
↓↓ strongly influential; increasing the parameter decreases the Tier 2 guideline
↓ somewhat influential; increasing the parameter decreases the Tier 2 guideline
↑↓ parameter may slightly increase or decrease Tier 2 guidelines, depending on other parameters
\- no influence
a parameter only has significant influence if unsaturated zone transport occurs
b parameter only has significant influence if depth to contamination is greater than slab/basement depth
c may result in land/water use restriction
d pathway is not available for Tier 2 Guideline Adjustment
e based on no lateral offset to receptor; parameter has strong decreasing effect with an offset distance
f effect is only strong if substance biodegrades in the subsurface

APPENDIX C TIER 2 MODIFICATIONS

C.1 Assumptions and Parameters

The assumptions and model parameters applied for the calculation of the Tier 1 guidelines form the starting point for any Tier 2 Guideline Adjustments. However, at Tier 2 it may be possible to exclude certain pathways, as discussed in Section 3 of Part B and in Section C.7 below, or to adjust the values of certain stable, readily measured parameters to reflect site-specific conditions. Model parameters which can be adjusted at Tier 2 include:

1. source length;
2. source width;
3. depth to contamination;
4. thickness of contamination;
5. depth to groundwater;
6. distance to surface water;
7. hydraulic gradient;
8. saturated hydraulic conductivity;
9. soil organic carbon content;
10. soil dry bulk density;
11. soil moisture content; and,
12. soil vapour permeability.

Details on the data requirements for adjusting these parameters are provided in Section C.7.

C.2 Ranges of Allowable Parameter Adjustment

Model parameters used for Tier 2 Guideline Adjustment generally have limited ranges over which they can vary. Ranges considered to be appropriate, for most Alberta sites, are summarized in Table C-1.

In some cases the ranges are approximate and reflect the range of values that are typically encountered at sites in Alberta. However, for some parameters the ranges are limited by physical constraints or by model assumptions or simplifications that limit the utility of the model outside the typical range. For instance, high moisture contents or large source areas tend to invalidate some of the simplifying assumptions used in the model development and therefore require additional considerations. High rates of transport (associated with high permeabilities) tend to invalidate laminar flow assumptions built into all transport models supplied here. Therefore, if parameter values outside the ranges in Table C-1 are measured at a site, strong supporting data is necessary to demonstrate that the model prediction is appropriate, particularly if it leads to increased Tier 2 remediation guidelines. For variable parameters, long term monitoring may be necessary

to justify any Tier 2 closure. Where the measured value is outside the range, it is possible to use Tier 2 Guideline Adjustment with a parameter input at the limit of the range.

C.3 Inter-dependence of Parameters

Many of the model parameters used for Tier 2 are linked to or affected by other parameters, and therefore cannot be adjusted independently. All potentially related parameters should be measured together.

Specific sets of linked parameters relevant at Tier 2 include:

1. Soil bulk density, moisture content, total porosity, air-filled porosity and water-filled porosity. The soil bulk density and moisture content are normally used to calculate the other values in this set of parameters. As noted in Section C.7 below, moisture content measurements must conservatively reflect seasonal and spatial variations. In most instances for the vapour inhalation pathway, it is more advisable to use the default moisture content rather than measuring the value due to the difficulty in determining long term variability in moisture content. If bulk density or total porosity are altered at Tier 2, then the default moisture content must be adjusted to reflect the ratio of air/water filled pore space in the default case. In all instances, the moisture content must never be set greater than 80% of the effective porosity due to the limitations of the vapor transport model.
2. Source dimensions (source length, source width, depth to contamination, thickness of contamination and depth to groundwater). The source dimension parameters can normally be readily determined from a combination of analytical results and survey data at delineated sites. While depth to groundwater is not a source dimension *per se*, it is used in conjunction with the depth to contamination and thickness of contamination to determine any vertical separation between the contamination and the saturated zone. Values must always be conservative estimates of dimensions. For instance, minimum separation distances between contaminant zone and groundwater, maximum thickness of contamination, maximum source length, width etc. must always be used as model inputs.
3. Hydraulic conductivity and hydraulic gradient. These parameters are often correlated. For sites in similar groundwater flow regimes, it is often observed that a higher conductivity results in a lower hydraulic gradient. Therefore, if one parameter is measured the other should be as well.

The linked parameters are summarized by pathway in Table C-2. Further details on the measurement of these parameters are provided in Section C.7.

Adjusting building parameters would normally imply future land use restrictions and therefore these parameters cannot be adjusted at Tier 2. The exception to this is if adjusting building parameters would result in less conservative guidelines than Tier 1. See Section C.5 for details.

C.4 Petroleum Hydrocarbon Fractions

The calculation for Petroleum Hydrocarbon Fractions is unique and must be taken into account for Tier 2 Guideline Modification.

Petroleum hydrocarbons are a complex mixture of substances. To facilitate the calculation of risk-based soil and groundwater remediation guidelines, each fraction has been divided into several sub-fractions on the basis of chemical structure (aliphatic vs. aromatic) and carbon chain length.

Soil or groundwater remediation guidelines for each PHC fraction were developed by combining guidelines for individual sub-fractions according to the equation below:

$$SGRG\ (mg/kg - bw/day) = \frac{1}{\sum_i \frac{F_i}{SGRG_i}}$$

Where:

SGRG	=	soil (mg/kg) or groundwater (mg/L) remediation guideline;
F_i	=	the assumed proportion of the fraction in soil or groundwater made up of sub-fraction i (dimensionless) and,
$SGRG_i$	=	soil (mg/kg) or groundwater (mg/L) remediation guideline for sub-fraction "i" (mg/kg).

The assumed proportion of each sub-fraction differs for soil and groundwater, since each sub-fraction partitions differently between soil and groundwater. Assumed sub-fraction distributions for soil and groundwater are provided in Table A-10. The assumed sub-fraction distributions in soil are adopted directly from CCME (2007a). The assumed sub-fraction distributions in groundwater are calculated from the soil values by making standard equilibrium partitioning assumptions and using the following equations:

$$G_i = F_{i(soil)} \frac{\rho_b}{\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)}$$

and

$$F_{i(groundwater)} = \frac{G_i}{\sum_i G_i}$$

Where:

G_i	=	proportion of fraction i in groundwater (before normalization; dimensionless);
$F_{i(soil)}$	=	proportion of fraction i in soil (Table A-10; dimensionless);
$F_{i(groundwater)}$	=	proportion of fraction i in groundwater (normalized; Table A-10; dimensionless);
ρ_b	=	dry soil bulk density (g/cm^3);
θ_w	=	moisture-filled porosity (dimensionless);
K_{oc}	=	organic carbon partition coefficient (L/kg);

f_{oc}	=	fraction of organic carbon (g/g);
H'	=	dimensionless Henry's Law Constant (dimensionless); and,
θ_a	=	vapour-filled porosity (dimensionless).

When using a Tier 2 Guideline Modification approach, attention must be maintained to duplicating the procedure on which the Tier 1 values were obtained. In this guideline values are calculated for each subfraction "i" and then the soil or water quality remediation guideline is calculated based on the summation formula above.

C.5 Models, Equations and Protocols for Use in Tier 2 Guideline Adjustment

C.5.1 Human Exposure Pathways

C.5.1.1 Direct Contact

The direct contact pathway cannot normally be adjusted at Tier 2 except in the case of evaluating a more conservative exposure scenario than the Tier 1 default. The model used to calculate the soil remediation guideline protective of the human direct soil contact (soil ingestion, dermal contact, and particulate inhalation) exposure pathway for the chemicals of potential concern is taken from CCME (2006a). Based on guidance in CCME (2006a) exposure via particulate inhalation was not considered for volatile compounds (IR_s was set to 0 kg/day for volatile chemicals in the equations below). Parameter values were discussed in Section 2, and default parameter values are summarized in Tables A-1 to A-9. Separate calculations are made for carcinogens and non-carcinogenic chemicals.

In some instances, the mechanism of toxicity may be different for the different exposure routes. In these instances, separate guidelines may be calculated based on specific exposure pathways for the gut, skin and particulate inhalation. This option is only available where separate values have been noted in the Tier 1 table for different exposure routes.

Soil guidelines must be protective of both long-term human exposures and potential risks associated with acute exposures to high concentrations of a contaminant in soil. Young children who ingest large amounts of soil (*pica* children) generally represent a worst-case scenario for acute exposures. Potential for acute exposure generally may be assessed using the same procedure but will require re-evaluation of the tolerable intake, based on a short-term exposure event and the exposure rates based on a maximum event.

Non-Carcinogens

$$SRG_{HDC} = \frac{(TDI - EDI) \times SAF \times BW}{\left[(AF_G \times SIR) + (AF_L \times IR_S \times ET_2) + (AF_S \times SR)\right] \times ET_1} + [BSC]$$

Where:

SRG_{HDC}	=	human health-based soil remediation guideline for direct contact (mg/kg);
TDI	=	tolerable daily intake (mg/kg bw per day);
EDI	=	estimated daily intake (mg/kg bw per day);
SAF	=	soil allocation factor (dimensionless);
BW	=	adult or toddler body weight (kg);
AF_G	=	absorption factor for gut (dimensionless);
AF_L	=	absorption factor for lung (dimensionless);
AF_S	=	absorption factor for skin (dimensionless);
SIR	=	adult or toddler soil ingestion rate (kg/day);
IR_S	=	inhalation of particulate matter re-suspended from soil (kg/day);
SR	=	adult or toddler soil dermal contact rate (kg/day);
ET_1	=	exposure term 1 (dimensionless) (days/week ÷ 7 x weeks/year ÷ 52);
ET_2	=	exposure term 2 (dimensionless) (hours/day ÷ 24); and,
BSC	=	background soil concentration (mg/kg).

Carcinogens

$$SRG_{HDC} = \frac{(RsD) \times BW}{\left[(AF_G \times SIR) + (AF_L \times IR_S \times ET_2) + (AF_S \times SR)\right] \times ET_1} + [BSC]$$

Where:

SRG_{HDC}	=	preliminary human health-based soil remediation guideline (mg/kg);
RsD	=	risk-specific dose (mg/kg bw per day);
BW	=	adult body weight (kg);
AF_G	=	absorption factor for gut (dimensionless);
AF_L	=	absorption factor for lung (dimensionless);
AF_S	=	absorption factor for skin (dimensionless);
SIR	=	adult soil ingestion rate (kg/day);
IR_S	=	inhalation of particulate matter re-suspended from soil (kg/day);
SR	=	adult soil dermal contact rate (kg/day);
ET_1	=	exposure term 1 (dimensionless) (days/week ÷ 7 x weeks/year ÷ 52);
ET_2	=	exposure term 2 (dimensionless) (hours/day ÷ 24); and,
BSC	=	background soil concentration (mg/kg).

Note that, in contrast to the CCME (2006a) protocol, an exposure term is permitted for commercial and industrial land use for carcinogens.

Where a detailed site-specific risk assessment is required and where the potential for exposure through inhalation of particulates (e.g. $(AF_L \times IR_S \times ET_2)$ term) has the potential to become a critical exposure route for the contaminant of concern, it will be necessary to re-evaluate the default IR_s term to ensure that it is protective for the potential exposure from contaminated soil suspended in air. For less detailed Tier 1 and Tier 2 model changes, this analysis is not necessary.

The soil dermal contact rate (SR) is the mass of contaminated soil that is assumed to contact the skin each day. This parameter is calculated as follows (CCME, 2006a):

$$SR = \{(SA_H \times DL_H) + (SA_O \times DL_O)\} \times EF$$

Where:

SR	=	soil dermal contact rate (kg/day);
SA_H	=	exposed surface area of hands (m2);
DL_H	=	dermal loading of soil to hands (kg/m2 per event);
SA_O	=	area of exposed body surfaces other than hands (m2);
DL_O	=	dermal loading of soil to other surfaces (kg/m2 per event); and,
EF	=	exposure frequency (events/day).

The soil dermal contact rate is calculated separately for toddlers and adults using the parameters in Table A-1.

C.5.1.2 Vapour Inhalation

Soil and groundwater guidelines protective of the indoor infiltration and inhalation pathway were calculated using the equations from the CCME (2006a) protocol without change for soil and adapted as appropriate for groundwater.

Consistent with the approach taken in CCME (2007a), an adjustment factor of 10 is applied in the equations below for petroleum hydrocarbons (including petroleum hydrocarbon fractions, benzene, toluene, ethylbenzene and xylenes), to account for empirical evidence demonstrating that measured indoor air concentrations are typically lower by at least an order of magnitude than concentrations predicted from the models below. The adjustment factor takes the value of 1 for all other chemicals, reflecting the lack of any empirical data to support such a factor for these chemicals. Parameter values were discussed in Section C.2, and default parameter values are summarized in Tables A-1 to A-9. Separate calculations are made for carcinogens and non-carcinogenic chemicals.

Soil Guidelines for Non-Carcinogens

$$SRG_I = \frac{(TC - C_a) \times [\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)] \times SAF \times DF_i \times 10^3 \times AF}{H' \times \rho_b \times ET \times 10^6} + BSC$$

Where:

SQG_I	=	soil remediation guideline for indoor infiltration (mg/kg);
TC	=	tolerable concentration (mg/m^3);
C_a	=	background air concentration (mg/m^3);
θ_w	=	moisture-filled porosity (dimensionless) for contaminated soil;
K_{oc}	=	organic carbon partition coefficient (L/kg);
f_{oc}	=	fraction of organic carbon (g/g) for contaminated soil;
ρ_b	=	dry soil bulk density (g/cm^3) for contaminated soil;
H'	=	dimensionless Henry's Law Constant (dimensionless);
θ_a	=	vapour-filled porosity (dimensionless) for contaminated soil;
SAF	=	soil allocation factor (dimensionless);
DF_i	=	dilution factor from soil gas to indoor air (calculated below);

10^3	=	conversion factor from kg to g;
AF	=	adjustment factor (10, hydrocarbons; 1, all other chemicals);
ET	=	exposure term (dimensionless);
10^6	=	conversion factor from m^3 to cm^3; and,
BSC	=	background soil concentration (mg/kg).

Soil Guidelines for Carcinogens

$$SQG_I = \frac{RsC \times [\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)] \times DF_i \times 10^3 \times AF}{H' \times \rho_b \times ET \times 10^6} + BSC$$

Where:

SQG_I	=	soil quality guideline for indoor infiltration (mg/kg);
RsC	=	risk-specific concentration (mg/m^3);
C_a	=	background air concentration (mg/m^3);
θ_w	=	moisture-filled porosity (dimensionless) for contaminated soil;
K_{oc}	=	organic carbon partition coefficient (L/kg);
f_{oc}	=	fraction of organic carbon (g/g) for contaminated soil;
ρ_b	=	dry soil bulk density (g/cm^3) for contaminated soil;
H′	=	dimensionless Henry's Law Constant (dimensionless);
θ_a	=	vapour-filled porosity (dimensionless) for contaminated soil;
DF_i	=	dilution factor from soil gas to indoor air (calculated below);
10^3	=	conversion factor from kg to g;
AF	=	adjustment factor (10, hydrocarbons; 1, all other chemicals);
ET	=	exposure term (dimensionless);
10^6	=	conversion factor from m^3 to cm^3; and,
BSC	=	background soil concentration (mg/kg).

Note that in contrast to the CCME (2006a) protocol, an exposure term of 0.2747 is used for commercial and industrial land use for carcinogens. This corresponds to an exposure term of 10 hours/day, 5 days/week and 48 weeks/year, consistent with the commercial and industrial exposure term for non-carcinogens.

Groundwater Guidelines for Non-Carcinogens

$$GWRG_I = \frac{(TC - C_a) \times SAF \times DF_i \times AF}{H' \times ET \times 10^3}$$

Where:

$GWRG_I$	=	groundwater remediation guideline for indoor infiltration (mg/L);
TC	=	tolerable concentration (mg/m^3);
C_a	=	background air concentration (mg/m^3);
SAF	=	soil allocation factor (dimensionless);
DF_i	=	dilution factor from soil gas to indoor air (calculated below);
AF	=	adjustment factor (10, hydrocarbons; 1, all other chemicals);
H′	=	dimensionless Henry's Law Constant (dimensionless);
ET	=	exposure term (dimensionless);
10^3	=	conversion factor from m^3 to L; and,

Groundwater Guidelines for Carcinogens

$$GWRG_I = \frac{RsC \times DF_i \times AF}{H' \times ET \times 10^3}$$

Where:

$GWRG_I$	=	groundwater remediation guideline for indoor infiltration (mg/L);
RsC	=	risk-specific concentration (mg/m^3);
DF_i	=	dilution factor from soil gas to indoor air (calculated below);
AF	=	adjustment factor (10, hydrocarbons; 1, all other chemicals);
H′	=	dimensionless Henry's Law Constant (dimensionless);
ET	=	exposure term (dimensionless);
10^3	=	conversion factor from m^3 to L; and,

Note that in contrast to the CCME (2006a) protocol, an exposure term of 0.2747 is used for commercial and industrial land use for carcinogens. This corresponds to an exposure term of 10 hours/day, 5 days/week and 48 weeks/year, consistent with the commercial and industrial exposure term for non-carcinogens.

Dilution Factor Calculation

The dilution factor (DF_i) is calculated as follows:

$$DF_i = \frac{1}{\alpha}$$

Where:

DF_i	=	dilution factor from soil gas concentration to indoor air concentration (unitless); and,
α	=	attenuation coefficient (unitless; see derivation below).

$$\alpha = \frac{\left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right)}{exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) + \left(\frac{D_T^{eff} A_B}{Q_B L_T}\right) + \left(\frac{D_T^{eff} A_B}{Q_{soil} L_T}\right)\left[exp\left(\frac{Q_{soil} L_{crack}}{D_{crack} A_{crack}}\right) - 1\right]}$$

Where:

α	=	attenuation coefficient (dimensionless);
D_T^{eff}	=	effective porous media diffusion coefficient (cm^2/s; calculated below);
A_B	=	building area (cm^2);
Q_B	=	building ventilation rate (cm^3/s; calculated below);
L_T	=	distance from contaminant source to foundation (cm);
Q_{soil}	=	volumetric flow rate of soil gas into the building (cm^3/s; calculated below);
L_{crack}	=	thickness of the foundation (cm);
D_{crack}	=	effective vapour diffusion coefficient through the crack (cm^2/s; calculated below); and,
A_{crack}	=	area of cracks through which contaminant vapours enter the building (cm^2).

Calculation of D_T^{eff}:

$$D_T^{eff} \approx D_a \times \left(\frac{\theta_a^{10/3}}{\theta_t^2} \right)$$

Where:

	D_T^{eff}	=	overall effective porous media diffusion coefficient based on vapour-phase concentrations for the region between the source and foundation (cm^2/s);
	D_a	=	diffusion coefficient in air (cm^2/s);
	θ_a	=	soil vapour-filled porosity (dimensionless); and,
	θ_t	=	soil total porosity (dimensionless).

Note that this equation assumes that the dominant form of diffusion is through air and therefore cannot be applied to scenarios where diffusion in water may become a dominant form of the transport equation. Therefore, moisture content must always be set to an unsaturated condition in order to apply this equation. It is up to the proponent to ensure that the moisture content is appropriate to the equation used. Further guidance may be obtained from Johnson (2002).

For Tier 1 and Tier 2 Guideline Adjustments where more than 1 stratum exists, the calculation of D_T^{eff} must be based on the most conservative stratum in the zone of contaminant migration (e.g., the stratum with the highest diffusion coefficient must be used). An exception is allowed for sites where a surficial fine grained deposit exists over a coarse grained deposit. The fine grained layer can be applied to the calculation of D_T^{eff} under the following conditions:

1. Sufficient borehole information is provided to support the presence of a continuous fine grained layer over the entire site,
2. Sufficient borehole information is provided to support estimation of the minimum thickness of the fine grained layer, and
3. The minimum thickness of the fine grained layer is at least 1 m below the depth of typical excavations at the site in the event of construction and at least 1 m below the maximum depth of basements or potential basements at the site.

Where this exception is applied, the depth to the contaminant layer or the groundwater in the model must be set to the minimum depth of the base of the fine grained layer.

For more detailed site-specific risk assessments and in the event that sufficient data is available to determine continuous presence of several layers and minimum and maximum thickness of these layers, it may be possible to estimate the effective diffusion coefficient based on a combination of all layers present at the site. However, this requires a site-specific risk assessment and is not allowed for simple model changes at Tier 2.

Calculation of D_{crack}:

D_{crack} is calculated in exactly the same way as D_T^{eff}, with the exception that the assumption is made that the soil material in the cracks is dry (CCME, 2006a), and accordingly, the air filled porosity is the same as the total porosity, and the equation becomes:

$$D_{crack} \approx D_a \times \left(\frac{\theta_t^{10/3}}{\theta_t^2} \right)$$

Where:
- D_{crack} = effective porous media diffusion coefficient in floor cracks (cm^2/s);
- D_a = diffusion coefficient in air (cm^2/s);
- θ_t = total porosity for underlying soil (dimensionless).

In this equation, it is always assumed that the soil properties are based on the properties of the soil surrounding the building foundation.

Calculation of Q_B:

$$Q_B = \frac{L_B W_B H_B ACH}{3{,}600}$$

Where:
- Q_B = building ventilation rate (cm^3/s);
- L_B = building length (cm);
- W_B = building width (cm);
- H_B = building height (cm 3);
- ACH = air exchanges per hour (h^{-1}); and,
- 3,600 = conversion factor from hours to seconds.

Calculation of Q_{soil}:

$$Q_{soil} = \frac{2\pi \Delta P k_v X_{crack}}{\mu \ln\left[\dfrac{2Z_{crack}}{r_{crack}}\right]}$$

Where
- Q_{soil} = volumetric flow rate of soil gas into the building (cm^3/s);
- ΔP = pressure differential ($g/cm \cdot s^2$);
- k_v = soil vapour permeability to vapour flow (cm^2) for soil adjacent to building foundation;
- X_{crack} = length of idealized cylinder (cm);
- μ = vapour viscosity (0.000173 $g/cm \cdot s$; CCME, 2006a);
- Z_{crack} = distance below grade to idealized cylinder (cm); and,
- r_{crack} = radius of idealized cylinder (cm; calculated as A_{crack}/X_{crack}).

C.5.1.3 *Ingestion of Produce, Meat and Milk*

At this time, the guidelines based on the ingestion of produce, meat and milk cannot be modified at Tier 2. For site-specific risk assessments, it is necessary to evaluate the potential risk for this pathway. Further details on the evaluation of this pathway can be found in CCME (2006a).

C.5.2 Ecological Exposure Pathways

C.5.2.1 Direct Soil Contact

At this time, soil guidelines based on direct contact by ecological receptors cannot be modified via Tier 2 Guideline Adjustment. Direct ecological toxicity testing for Tier 2 Site Specific Risk Assessment is available for specific compounds (e.g. petroleum hydrocarbons, benzene, toluene, ethylbenzene, xylenes) where toxicity testing protocols are clearly defined and can be replicated in site-specific instances. Alberta Environment should be consulted prior to site-specific modifications of this pathway.

The groundwater remediation guidelines for the direct ecological soil contact pathway for non-polar organic compounds are based on partitioning of the substance from soil to water described as follows:

Non-polar organic compounds

$$GWRG_{DC} = SRG_{DC} \frac{\rho_b}{\theta_w + (K_{oc} \times f_{oc} \times \rho_b) + (H' \times \theta_a)}$$

Where:

$GWRG_{DC}$	=	groundwater remediation guideline protective of direct contact with plants and soil invertebrates in areas of shallow groundwater (mg/L);
SRG_{DC}	=	soil remediation guideline protective of direct contact with plants and soil invertebrates (mg/kg);
ρ_b	=	dry soil bulk density (g/cm^3);
θ_w	=	moisture-filled porosity (dimensionless);
K_{oc}	=	organic carbon partition coefficient (L/kg);
f_{oc}	=	fraction of organic carbon (g/g);
H'	=	dimensionless Henry's Law Constant (dimensionless); and,
θ_a	=	vapour-filled porosity (dimensionless).

C.5.2.2 Soil and Food Ingestion

Soil guidelines based on soil and food ingestion by livestock and wildlife cannot be modified at Tier 2 at this time. Where site-specific risk assessments are conducted, it may be necessary to re-evaluate this pathway to ensure protection of sensitive receptors.

C.5.3 Groundwater Pathways

C.5.3.1 Soil Remediation Guidelines

Soil remediation guidelines for groundwater pathways were calculated using the model and equations from the CCME (2006a) protocol. Soil remediation guidelines for the protection of groundwater are not calculated for inorganic substances due to the uncertainties associated with the partitioning of metals between the adsorbed and dissolved phase. Inorganic substances should be assessed through site-specific groundwater sampling where these pathways are applicable.

Assumptions implicit in the model include the following:

1. the soil is physically and chemically homogeneous;
2. moisture content is uniform throughout the unsaturated zone;
3. infiltration rate is uniform throughout the unsaturated zone;
4. depletion of the contaminant source is not considered (*i.e.*, infinite source mass);
5. flow in the unsaturated zone is assumed to be one dimensional and downward only (vertical recharge) with dispersion, sorption-desorption, and biological degradation;
6. contaminant is not present as an immiscible phase product;
7. maximum possible concentration in the leachate is equivalent to the solubility limit of the chemical in water under the defined site conditions;
8. groundwater aquifer is unconfined;
9. groundwater flow is uniform and steady;
10. co-solubility and oxidation/reduction effects are not considered;
11. attenuation of the contaminant in the saturated zone is assumed to be one-dimensional with respect to sorption-desorption, dispersion, and biological degradation;
12. dispersion in groundwater is assumed to occur in the longitudinal and transverse directions only and diffusion is not considered;
13. mixing of the leachate with the groundwater is assumed to occur through mixing of leachate and groundwater mass fluxes; and
14. dilution of the plume by groundwater recharge down-gradient of the source is not included.

The soil remediation guideline protective of groundwater uses is calculated in the same way for all five groundwater uses noted in Section 3.3 of Part A, using the corresponding water quality guidelines as the starting point for each, with two exceptions. The first exception is that the lateral offset between the point at which the contaminated soil is measured and the surface water body (parameter "x" in the dilution factor 4 equation below) is assumed to be 10 m for aquatic life and wildlife watering, and zero for the other water uses. Therefore, dilution factor 4 is only active for aquatic life and wildlife watering and cannot be applied for other pathways. The second exception is that in the calculation of dilution factor 3 for the potable groundwater pathway only, the average thickness of the mixing zone (Z_d) takes the fixed value of 2 m, reflecting the likely minimum screen length for a viable drinking water well. It should be noted that this second point reflects Alberta Environment policy and is not consistent with CCME (2006a).

The model considers four processes:

1. partitioning of the substance from soil to pore water (leachate);
2. transport of the leachate from the base of contamination to the groundwater table;
3. mixing of the leachate with groundwater; and,

4. transport of the substance in groundwater down-gradient to a discharge point.

For each of these four processes, a dilution factor was calculated (DF1 through DF4, respectively). DF1 has units of (mg/kg)/(mg/L) or L/kg. The other three dilution factors are dimensionless [units of (mg/L)/(mg/L)]. The overall dilution factor is used to calculate the soil concentration that is protective of groundwater using the following equations:

$$SRG_{GR} = SWQG_{FL} \times DF$$

$$DF = DF1 \times DF2 \times DF3 \times DF4$$

Where:

SRG_{GR}	=	soil remediation guideline protective of groundwater pathways (mg/kg);
$SWQG_{FL}$	=	corresponding surface water quality guideline (drinking water, aquatic life, livestock or wildlife watering, or irrigation) (mg/L);
DF	=	overall dilution factor (L/kg);
DF1	=	dilution factor for process 1 (L/kg);
DF2	=	dilution factor for process 2 (L/L);
DF3	=	dilution factor for process 3 (L/L); and,
DF4	=	dilution factor for process 4 (L/L).

Dilution Factor 1

Dilution factor 1 (DF1) is the ratio of the concentration of a contaminant in soil to the concentration in leachate that is in contact with the soil. This "dilution factor" represents the three phase partitioning between contaminant sorbed to soil, contaminant dissolved in pore water (*i.e.*, as leachate), and contaminant present as soil vapour. DF1 is calculated using the following equation:

$$DF1 = K_{oc} \times f_{oc} + \frac{(\theta_w + H' \times \theta_a)}{\rho_b}$$

Where:

DF1	=	dilution factor 1 (L/kg);
K_{oc}	=	organic carbon-water partition coefficient (L/kg);
f_{oc}	=	fraction organic carbon (g/g) of the contaminated soil;
θ_w	=	water filled porosity (dimensionless) of the contaminated soil;
H'	=	dimensionless Henry's Law constant (dimensionless);
θ_a	=	air filled porosity (dimensionless) of the contaminated soil; and,
ρ_b	=	dry soil bulk density (g/cm^3) of the contaminated soil.

Dilution Factor 2

Dilution factor 2 (DF2) is the ratio of the concentration of a contaminant in leachate that is in contact with the soil, to the concentration in pore water just above the groundwater table. DF2 takes the value 1.00 (*i.e.,* no dilution) for generic guidelines because it is assumed at Tier 1 that the contaminated soil extends down to the water table. However, at

Tier 2 a calculated value can be used for DF2 if the contaminated soil is not in contact with the groundwater:

$$DF2 = \frac{1}{\exp\left[\frac{b}{2\partial_u} - \frac{b}{2\partial_u}\left(1 + \frac{4\partial_u L_{US}}{v_u}\right)^{1/2}\right]}$$

$$v_u = \frac{I}{\theta_w R_u}; \quad R_u = 1 + \frac{\rho_b}{\theta_w} K_{oc} f_{oc}$$

DF2	=	dilution factor 2 (dimensionless)
b	=	thickness of unsaturated zone below the source (m) = d – Z
d	=	depth from surface to groundwater surface (m)
Z	=	depth to bottom of contaminated soil (m)
∂_u	=	dispersivity in the unsaturated zone (m) = 0.1b
L_{US}	=	decay constant for chemical (y^{-1}) in unsaturated zone:

$$L_{US} = \frac{0.693}{t_{1/2US}}\left(e^{-0.07d}\right)$$

$t_{1/2US}$	=	chemical half-life in unsaturated zone (years)
v_u	=	average linear leachate velocity (m/y)
I	=	infiltration rate (m/y)
θ_w	=	water-filled porosity (unitless) in unsaturated zone;
R_u	=	retardation factor in unsaturated zone (unitless)
ρ_b	=	soil bulk density in unsaturated zone (g/cm^3)
K_{oc}	=	organic carbon-water partition coefficient (L/kg); and,
f_{oc}	=	fraction organic carbon (g/g) in unsaturated zone;

<u>Dilution Factor 3</u>

Dilution factor 3 (DF3) is the ratio of the concentration of a chemical in pore water just above the groundwater table, to the concentration in groundwater beneath the source. This dilution factor reflects a decrease in concentration as leachate mixes with uncontaminated groundwater. DF3 is a function of groundwater velocity, infiltration rate, source length, and mixing zone thickness. The mixing zone thickness is calculated as being due to two processes: i) mixing due to dispersion, and ii) mixing due to infiltration rate. The equations used are as follows:

$$DF3 = 1 + \frac{Z_d \times V}{I \times X}$$

$$Z_d = r + s$$

$$r = 0.01 \times X$$

$$s = d_a\left\{1 - exp\left(\frac{-2.178 \times X \times I}{V \times d_a}\right)\right\}$$

$$V = K \times i$$

Where:

DF3	=	dilution factor 3 (dimensionless);
Z_d	=	average thickness of mixing zone (m);
V	=	Darcy velocity in groundwater (m/year);
I	=	infiltration rate (m/year);
X	=	length of contaminated soil (m);
r	=	mixing depth due to dispersion (m);
s	=	mixing depth due to infiltration rate (m);
d_a	=	unconfined aquifer thickness (m);
K	=	aquifer hydraulic conductivity (m/year); and,
i	=	lateral hydraulic gradient in aquifer (dimensionless).

Note that the parameter Z_d takes the fixed value of 2 m for the drinking water pathway, but is calculated as above for all other pathways.

Dilution Factor 4

Dilution factor 4 (DF4) accounts for the processes of dispersion and biodegradation as groundwater travels downgradient from beneath the source of contamination, and is the ratio of the concentration of a chemical in groundwater beneath the source, to the concentration in groundwater at a distance (10 m for Tier 1 for aquatic life and wildlife watering) downgradient of the source. For distances less than 10 m, a value of 1 should be used for DF4. Consistent with CCME (2006b), the time independent (steady state) version of the equation to calculate DF4 was used:

$$DF4 = \frac{2}{\exp(A) \times [erf(C) - erf(D)]}$$

$$A = \frac{x}{2D_x}\left\{1 - \left(1 + \frac{4L_s D_x}{v}\right)^{1/2}\right\}$$

$$C = \frac{y + Y/2}{2(D_y x)^{1/2}}$$

$$D = \frac{y - Y/2}{2(D_y x)^{1/2}}$$

$$L_s = \frac{0.6931}{t_{1/2s}} \times \exp(-0.07d)$$

$$v = \frac{V}{\theta_t R_s}$$

$$R_s = 1 + \frac{\rho_b K_{oc} f_{oc}}{\theta_t}$$

$$D_x = 0.1x$$

$$D_y = 0.01x$$

Where:

DF4	=	dilution factor 4 (dimensionless);
erf	=	the error function;
A	=	dimensionless group A (dimensionless);
C	=	dimensionless group C (dimensionless);
D	=	dimensionless group D (dimensionless);
x	=	lateral distance between source and receptor (m);
D_x	=	dispersivity in the direction of groundwater flow (m);
L_s	=	decay constant (1/year);
v	=	velocity of the contaminant (m/year);
y	=	distance to receptor perpendicular to groundwater flow (m);
Y	=	source width (m);
D_y	=	dispersivity perpendicular to the direction of groundwater flow (m);
$t_{1/2s}$	=	decay half-life of contaminant in saturated zone of aquifer (years);
d	=	water table depth (m);
V	=	Darcy velocity in groundwater (m/year);
θ_t	=	total soil porosity (dimensionless) in the aquifer;
R_s	=	retardation factor in saturated zone (dimensionless);
ρ_b	=	dry soil bulk density in the aquifer (g/cm^3);
K_{oc}	=	organic carbon partition coefficient (mL/g); and,
f_{oc}	=	fraction organic carbon (g/g) in the aquifer.

Groundwater Remediation Guidelines

It is assumed that a dugout could potentially be constructed at any location on agricultural land and, accordingly, the livestock watering and irrigation water quality guidelines are applicable as groundwater remediation guidelines across all agricultural land. Furthermore, it is assumed that a water well could be constructed anywhere within a Domestic Use Aquifer (DUA) (see Appendix E). Accordingly, the drinking water quality guidelines must be applied as groundwater remediation guidelines within the entire DUA. Therefore any modification of these guidelines is considered Exposure Control.

For aquatic life or wildlife watering, it is assumed that there is a minimum 10 m lateral separation between the point of measurement and the surface water body; this distance can be modified at Tier 2.The groundwater remediation guideline protective of aquatic life and wildlife watering is calculated using the following equations.

$$GWRG_{GR} = SWQG \times DF4$$

Where: $GWRG_{GR}$= groundwater remediation guideline protective of groundwater pathways (mg/kg);
$SWQG_{FL}$= corresponding surface water quality guideline (aquatic life, or wildlife watering) (mg/L);
DF4 = dilution factor for process 4 (L/kg).

DF4 is calculated as above.

C.6 Site-Specific Adjustments Not Supported at Tier 2

Several parameters that may have an influence on the fate and exposure models cannot normally be modified at Tier 2:

1. Human receptor characteristics have been selected by Health Canada as representative of the Canadian population based on the best available data and are therefore not adjustable at Tier 2. An exception is made if there is reason to believe that the characteristics of human activity lead to greater exposure than used in the default assumptions. In this instance, a site-specific risk assessment should be employed that incorporates the use of the more sensitive receptor characteristics. For instance, where the consumption of food from the area is greater than for the average population, it is necessary to conduct a Tier 2 adjustment to account for this increased risk.
2. Exposure scenarios have been selected to represent typical land uses. While in some cases it may be acceptable to adjust exposure scenarios while the proponent retains ongoing control of the site this requires administrative controls to ensure the exposure scenario is maintained and therefore requires use of the Exposure Control option. If the exposure scenario at a site is believed to be more conservative than the default for the appropriate land use, it may be possible to use a more conservative land use that captures the appropriate exposure scenario. If this is not possible, a site-specific evaluation is undertaken that will recalculate the guidelines based on the more sensitive exposure scenario.
3. Receptor locations (e.g. lateral offsets to buildings or potable water wells) cannot be adjusted at Tier 2. Use of lateral offsets requires Exposure Control since future receptor locations can change. The exceptions are the distance to a surface water body that is fixed or the distance to a building more sensitive than the default scenario (as discussed below). The presence of large diameter bored wells in low permeability soil can also be considered under a lateral offset. For details, see Section 3.2 and Appendix E. For Exposure Control scenarios, it is possible to use calculations based on current receptor locations to justify the ongoing administrative or technical controls.
4. Building properties are based on typical construction practices. Since Tier 2 objectives must be protective of future as well as existing buildings, adjustment of building properties is not normally allowed at Tier 2. The exception is if a building more sensitive than that normally assumed is currently present at the site (e.g., a building without a concrete foundation or a building with a very low air exchange rate). In this case, Tier 2 objectives must be calculated separately for both the default

building and the current building cases, with the lowest calculated objectives being applied. The calculations for the current building can be performed based on the current location of the building in this case only; the calculations for the default building would be performed based on a hypothetical building placed directly above the contamination.

5. Recharge (infiltration) rate is strongly affected by landscape and soil properties as well as rainfall, and therefore cannot be adjusted at Tier 2. An exception is made in the case of heterogeneous soil stratigraphy when there is a continuous fine-textured soil layer overlying a coarse-textured aquifer. Only in this case can the fine soil recharge rate be applied at a site otherwise classified as having coarse-textured soils. The proponent must demonstrate that the fine soils are continuous above the entire contaminated area and of sufficient thickness to reduce the infiltration rate. A minimum thickness of 1 m is required across the entire site to apply this correction.

C.7 Conditions Where Site-specific Risk Assessments are Required.

Tier 2 procedures presented herein are appropriate for sites that are fundamentally similar to the Tier 1 assumptions and are not applicable for sites that have significantly different properties. In these instances, it is necessary to conduct a site-specific risk assessment at Tier 2 rather than moving to simple Tier 2 model modifications. Specific conditions that will lead to Tier 2 guideline model adjustments not being applicable include:

The Presence of Preferential Flow Paths

Fate and transport models applied for Tiers 1 and 2 are based on transport through porous media (i.e. unconsolidated soils), and are not appropriate for modeling transport through bedrock fractures. For small fractures, it may still be possible to apply Tier 1 or Tier 2 approaches. Site-specific risk assessment is required where flow paths in the fractured bedrock cannot reasonably be expected to behave similarly to those in an aggregated soil medium. When fracture length exceeds approximately 2 cm, flow paths in the fractured bedrock may be different than those in an aggregated soil medium and the use of Darcy equation in describing flow needs to be re-evaluated. Where fracture planes are large enough that the principles of Darcy flow cannot be guaranteed, site specific risk assessment is required. In all cases, health and ecological protection objectives must be maintained.

Other preferential flow paths may be present that mitigate direct application of Tier 2 processes. Where a preferential flow path may exist, it needs to be assessed prior to application of generic transport models. Where the model is not appropriate, a Tier 2 SSRA approach is warranted. For instance, small lenses or utility corridors comprised dominantly of coarse textured materials may act as preferential flow paths, particularly where direct transport from the zone of contamination to the receptor of interest beyond Tier 1 or Tier 2 assumptions occurs.

Source of Contamination Within 30 cm of an Existing Building

The Johnson and Ettinger (1991) model is not considered reliable for contamination very close to the building (Golder, 2004). Therefore, for contamination within 30 cm of a

hypothetical or existing building foundation, a site-specific risk assessment approach to evaluate volatile organic compound transport into the building should be applied. Alternatively, an attenuation factor of 0.01 (i.e. a dilution factor of 100 from soil gas to indoor air) can be applied at Tier 2 instead of the site specific risk assessment.

Groundwater Flow to Stagnant Water Bodies

Additional consideration is required if groundwater at a site has the potential to discharge to a stagnant water body. A stagnant water body is defined as a water body without significant outflow, and where the main pathway of water loss is via evaporation. Stagnant water bodies will tend to concentrate discharging groundwater contaminants through evaporation. Water bodies with no obvious or known outflow should be considered stagnant. If outflow is suspected via groundwater and no obvious surface outflow is present, a groundwater investigation will be needed to provide confirmation.

In the assessment of whether soil or groundwater contaminants are likely to have an adverse effect on a stagnant surface water body, the concentrations of contaminants in groundwater are less important than the long-term effect on contaminant concentrations in the stagnant water body. Accordingly, when there is the potential for a contaminant in groundwater at a site to discharge to a stagnant surface water body, a SSRA is required for a mass balance assessment of the likely effect on the concentrations of that contaminant in the stagnant water body over the anticipated lifetime of the groundwater discharge in addition to other considerations for the water body. The assessment should take into consideration, in a qualitative sense, the likelihood of other potential future contaminant releases to the stagnant surface water body. Unless the effect on contaminant concentrations in the stagnant surface water body can be shown to be insignificant, remedial action will be required.

Greater Exposure than Considered at Tier 1

In some cases receptors at the site may experience much greater exposure than what is assumed at Tier 1 or Tier 2. In these instances, a more detailed site-specific risk assessment may be required to demonstrate that the appropriate sensitive receptor or land use is protected at the generic levels or the required remediation guidelines will need to be adjusted accordingly. In some instances, this may be dealt with through a Tier 2 Guideline Adjustment. For instance, where the concern is over food ingestion from the site, it may be possible to account for increased exposure by using the model at Tier 2 and modifying the food ingestion rates.

Sensitive Ecological Habitats

The Tier 1 ecological soil contact values are based on a level of protection deemed to be appropriate for most land uses. However, they may not be sufficiently protective of very sensitive ecological habitats or potential for sensitive land uses. The presence of a sensitive ecological habitat generally warrants a site-specific risk assessment.

C.8 Data Requirements for Tier 2 Modification

Tier 2 modification requires more detailed site data than a typical Tier 1 assessment.

C.8.1 Contaminant Characterization

Detailed contaminant characterization is required at Tier 2, including the extent of contamination. Lateral and vertical delineation of the contamination must be supported by appropriate laboratory analyses. Sites that are not fully delineated (e.g. lateral and vertical extent of contaminated zone is fully delineated and can be mapped) are not be eligible for Tier 2 modifications since the assumptions for modifications cannot be supported by site information. In addition, information is needed to support Tier 2 decisions over and above contaminant characterization. Specific information that may be needed for Tier 2 modification includes:

1. Source length – For the purpose of the groundwater model only, the source is defined as anything that adds contaminant mass to the groundwater since the model only considers contamination that enters the groundwater pathway. The model requires the total length of the contaminant source in the direction parallel to the primary direction of groundwater flow. If the direction of groundwater flow cannot be reliably determined or is variable, the longest dimension of the source must be used to represent the source length. The source length is determined from soil analytical data, and is used for all groundwater protection pathways. Increased source length reduces the Tier 2 levels. A source length greater than the Tier 1 default (10 m) leads to an automatic requirement for Tier 2 or higher assessment unless the contaminant delineation shows that the volume is less than 300 m^3.
2. Source width – the total length of the contaminant plume in the direction normal to the primary direction of groundwater flow. If the direction of groundwater flow cannot be reliably determined or is variable, the longest dimension of the plume should be used to represent the source width. The source width is determined from soil analytical data, and is used to calculate the guidelines for the groundwater protection pathways if there is separation between the contamination and the receptor. Source width is generally not a highly sensitive parameter in the groundwater model.
3. Depth to soil contamination – the distance from grade to the contamination. The depth to contamination is determined based on soil borehole and analytical data; if it varies across a site, the shallowest depth to contamination should be used. It is used for Tier 2 evaluation of the vapour inhalation pathway, in combination with other parameters. Depth to contamination may also affect the groundwater protection pathways and influence site management strategies.
4. Thickness of soil contamination – the distance from the top of the contamination to the bottom of the contamination. The contamination thickness is determined based on soil analytical data. It is used in combination with the depth to soil contamination and depth to groundwater to determine the separation distance (if any) between the contamination and groundwater. Where this depth is used to determine a separation distance between the soil and groundwater, a detailed delineation of the depth of soil contamination and groundwater depth must both be performed in and around the contaminant zone. The depth to soil contamination in combination with the thickness of soil contamination must be set in such a way that it describes the minimum distance between the groundwater and the base of the contaminant zone. The site specific information on contaminant thickness must reliably predict the maximum

contaminant thickness. If this cannot be reliably determined, zero separation distance to the groundwater must be assumed.

C.8.2 Physical Site Conditions

Several physical site characteristics are used in the fate and transport models applied at Tier 2, and should therefore be measured when appropriate.

Depth to groundwater

Depth to groundwater is the distance from grade to the water table. The depth to the water table may vary and there may be more than one aquifer at the site; for most Tier 2 purposes, the seasonal high water table in the shallowest aquifer is the most important. Depth to groundwater is normally measured using appropriately screened monitoring wells which have been given sufficient time to reach equilibrium While observations from soil borings are often useful to help identify the anticipated water table location, they are not considered reliable enough to specify the depth to groundwater at Tier 2. The depth to groundwater is used for calculating vapour inhalation-based groundwater objectives and for all protection of groundwater exposure pathways. Normally the shallowest depth to groundwater is used in these calculations. However, depth to groundwater at other locations is also used to determine the hydraulic gradient (below).

Information on depth to groundwater must reliably estimate both the mean depth and the variation both spatially and temporally across the site. In modeling, conservative estimates of the parameter in question (e.g. estimates resulting in the most conservative risk-based guidelines) are always required. Where groundwater depth has the potential to vary considerably over time, the highest potential water table must be used in estimating depth to the water table.

Distance to surface water

Distance to surface water is the distance between the edge of the contamination and the nearest surface water body. Increased distance to surface water results in increased Tier 2 objectives for the protection of aquatic life and wildlife watering. Any permanent or seasonal water body that may support aquatic life must be considered. For the purpose of the wildlife watering pathway, any permanent or seasonal water body must be considered regardless of potential to support aquatic life.

Distance to surface water must be measured from the minimum distance to a stable or decreasing contaminant zone from the flood risk area of the water body. Where the contaminant zone is within the flood risk area, a separation distance of 0 may be necessary.

Hydraulic gradient and saturated hydraulic conductivity

Hydraulic gradient and hydraulic conductivity cannot be assessed independently; both are required if Tier 2 changes to one parameter are anticipated. The amount of information needed for any Tier 2 alterations is dependant on site characteristics. However, a minimum of 3 monitoring wells is required for simple sites with small plumes and simple

(single unit) stratigraphies. In other circumstances, additional monitoring wells are always required. In all instances, monitoring must be sufficient to completely describe water table depth, flow direction and Darcy's velocity and variability in these parameters across the entire area of concern. Model inputs must always assume conservative estimates (e.g. estimates leading to conservative risk based guidelines) rather than mean estimates of the Darcy's velocity for the pathway of interest. Where only the minimum 3 points are available, inputs are always based on the most conservative value of the 3 measurements.

Hydraulic gradient describes the slope of the groundwater surface, based on measured groundwater elevations across the site. The hydraulic gradient must be measured over an area representative of the entire area of interest, capturing all potential exposure pathways, and be relevant to the aquifer of concern. The hydraulic gradient is used with the saturated hydraulic conductivity to determine the groundwater velocity and the velocity of dissolved contaminants. The hydraulic gradient is used for all groundwater protection pathways.

Saturated hydraulic conductivity is a measure of how easily water can flow through the soil, usually measured by performing bail tests or slug tests on a monitoring well, but also sometimes measured in the laboratory on undisturbed soil samples. Hydraulic conductivity is measured for the soil strata through which groundwater is flowing, especially more permeable strata which may dominate groundwater flow. If measured from a monitoring well, the well must be screened across the stratum of interest.

For anisotropic media, the saturated hydraulic conductivity must appropriately characterize the flow direction of importance. In general, this means that lateral flow within the aquifer will be of most importance except where vertical separation from a DUA is being demonstrated, in which case vertical flow becomes of greater importance. For heterogeneous media, the hydraulic conductivity should be estimated based on the most likely zone that will dominate groundwater flow. In most instances, this means that the medium with the highest conductivity will control groundwater transport and must be used except where this is a small, discontinuous layer.

Soil organic carbon fraction

Soil organic carbon is the fraction of soil by weight comprised of organic carbon (weight of organic carbon/weight of soil). The organic carbon content of the contaminated soil type (for vapour inhalation and groundwater protection pathways) and of any aquifers through which contaminants may migrate (for groundwater protection pathways) is a key parameter for calculating Tier 2 soil objectives. The organic carbon content must not be measured in soils contaminated with high concentrations of organic chemicals, since this may result in a false high reading. Rather, it must be measured in the same soil type at the same depth, but outside the contaminant source area. At least three samples from each soil stratum of interest are normally required, with increasingly more samples being required for large contaminant zones or aquifer flow paths or sites with complex stratigraphy (more than one stratigraphic unit) represented by the contaminant zone.

Organic carbon content must be sufficiently characterized to demonstrate both the mean and the variability in the organic matter present in the stratum of interest and allow for a conservative estimate of organic carbon for the site. Where only three samples are available, the most conservative value (the value resulting the most conservative estimate of the Tier 2 guidelines) is used.

Field sampling of organic carbon must be appropriate to the desired use in the Tier 2 model. For changes to the groundwater model, this means that measurements must characterize the organic carbon content from the contaminant zone to the receptor of interest and allow for a conservative estimate of organic carbon content across the entire area. For use in chemical partitioning from the groundwater to air (for the vapour inhalation pathway), organic carbon fraction must be representative of the contaminant zone and be taken from appropriate vertical and horizontal locations to characterize this layer without interference from the contaminant zone.

The organic carbon fraction is measured in a laboratory. It is essential that organic carbon (as opposed to total carbon or inorganic carbon) is reported.

Partitioning estimates based on models provided in this document assume linear partitioning with relatively uniform organic carbon materials, usually based on K_{oc}/K_{ow} relationships. As such, these estimates are only appropriate for mineral soils and for soils where organic materials are relatively uniformly mixed throughout the deposit. High organic soils may not have the same K_{oc}/K_{ow} relationships.

Where the organic carbon is heterogeneously located throughout the deposit (e.g. in the case of coal flecks in a stratum of interest), application of model changes at Tier 2 based on organic carbon content are not permitted.

In both these instances, although the deposit may afford additional protection not taken into account by the model, it is necessary to proceed to site-specific risk assessment with appropriate monitoring to demonstrate the additional protection offered by the stratum of interest.

Soil dry bulk density

The mass of soil per unit volume, measured from undisturbed soil samples or by geophysical methods. This parameter is related to total soil porosity, and, along with water content, affects the moisture-filled porosity and air-filled porosity. As a result, bulk density has indirect effects on both vapour transport and groundwater transport with higher bulk density resulting in reduced contaminant transport. Bulk density also affects partitioning calculations with higher bulk density leading to higher calculated dissolved-phase and vapour-phase chemical concentrations.

Depending on the distance between the contaminant source and receptors, higher bulk density can lead to either higher or lower Tier 2 objectives. Soil bulk density is relevant for both the soil strata in which contamination resides and all strata through which contaminant transport potentially occurs. In addition, soil bulk density indirectly affects

total porosity, air filled porosity and moisture filled porosity. Therefore the measurement will need to be appropriate to the point of interest.

There are 4 locations where soil bulk density measurements may come into play. These locations include:

1. Vapour inhalation: the zone between the contaminant zone and the zone immediately next to the building (as it affects porosity and air filled porosity).
2. Vapour inhalation and groundwater pathways: partitioning immediately at the contaminant zone.
3. Groundwater pathways: the zone between the contaminant and the groundwater table (only applies if a vertical separation distance between the contaminant zone and the groundwater is applied)
4. Groundwater pathways: the zone of transport along the aquifer (only applies to pathways where a horizontal separation distance is allowed).

As some of these inputs have little or no influence on the outcome, it may be advisable to conduct a sensitivity analysis to ensure that measurements are taken from the locations that have potential to influence the model outcome. This analysis should include factors that are influenced by bulk density (e.g. air filled porosity, moisture filled porosity, total porosity). Where the model is relatively insensitive to changes, default inputs can be used rather than conducting direct measurements.

As with other parameters, a minimum of 3 measurements are required in the appropriate zone for simple stratigraphies and small contaminant zones. For more complex sites, additional measurements are required to fully describe the expected range for the site. Conservative inputs must always be used in model calculations. Where only 3 measurements are available, the value resulting in the most conservative outcome must be applied.

For the zone of transport along the vapour inhalation pathway, the measurement of bulk density and porosity must represent the point resulting in the most conservative input along the transport path. In most instances for homogeneous media, this means that measurements will need to be taken near surface (above 0.5 m depth) to represent the typical conservative zone for a slab on grade foundation. However, there are some instances for heterogeneous media where this may require deeper measurements to capture a zone that represents a faster potential rate of contaminant transport than that immediately near the surface.

Soil moisture content (unsaturated zone)

The mass of water per mass of soil. Soil moisture content may be measured on either a volume per unit volume or mass per unit mass basis. These two calculations lead to very different values that are related through the soil bulk density. It is up to the proponent to ensure that the appropriate units are applied depending on the structure used in the model.

Along with the dry bulk density, moisture content affects the moisture-filled porosity and air-filled porosity. It has similar effects on Tier 2 vapour inhalation objectives as bulk density (i.e. higher water content generally increases Tier 2 objectives if there is a significant distance between the contamination and receptor, but may decrease Tier 2 objectives if there is very little separation). Soil water content is included in the models in three areas:

1. Vapour inhalation and groundwater pathways: partitioning immediately at the contaminant zone.
2. Groundwater pathways: the zone between the contaminant and the groundwater table (only applies if a vertical separation distance between the contaminant zone and the groundwater is applied)
3. Groundwater pathways: the zone of transport along the aquifer (only applies to pathways where a horizontal separation distance is allowed).

Moisture content can be measured in a laboratory by measuring the mass of soil before and after drying. However, since water content may vary both spatially and temporally, sufficient samples to represent all soils of interest would be required, and enough sampling must be taken to measure seasonal variation of moisture content. In most instances, field-based monitoring equipment that can continuously monitor moisture changes or other similar long term monitoring programs to accurately assess field moisture content are recommended.

Moisture content may be lower beneath buildings, so samples collected outside the footprint of existing buildings may not reflect conditions beneath a building if vapour transport with a depth to contamination greater than the default is being modeled. Additionally, moisture contents measurements in the zone of transport for the vapour inhalation pathway must be made for the most conservative point on the path of transport unless a more detailed site-specific risk assessment with long term monitoring is employed. In most instances, this means that moisture measurements for this pathway must be consistent with the theoretical depth below a slab on grade foundation (e.g. shallower than 50 cm) as this represents the zone of lowest moisture content as well as the zone with highest potential variation (e.g. highest rates of evapotransportation). It is also noted that data must be sufficiently large to estimate the seasonal variation in moisture content at this depth and apply a conservative estimate of the moisture content.

For most applications, use of moisture contents other than the default for the vapour inhalation pathway are not recommended due to the difficulty in obtaining a defensible data set and demonstrating conservative estimates of near surface values that are significantly different than the default scenario. For deep contaminant zones where the majority of transport is through specific geological deposits that have relatively stable moisture contents (e.g. are well outside the soil profile influenced by evapotranspiration), it is more likely possible to adequately assess the moisture content. However, this requires a site-specific risk assessment, including a more detailed evaluation of the stratigraphy of the site.

Where bulk density and total porosity are modified based on site-specific data the default moisture content may be applied but it must be recalculated to ensure consistency with the ratio of moisture filled porosity to total porosity in the appropriate soil texture category.

Soil vapour permeability

Soil vapour permeability is a measure of how easily vapours flow through the soil. This parameter has a strong influence on the vapour inhalation pathway, with a higher soil vapour permeability resulting in lower Tier 2 objectives. Vapour permeability can be measured in the field with pneumatic tests. However results of these tests have been shown to be affected by the distance between monitoring points. Field measurements may be influenced by moisture content and may not represent the potential permeability associated with the building. Therefore, field measurements must account for these variabilities.

Soil vapour permeability can be estimated as a function of hydraulic conductivity, water content and total soil porosity (US EPA, 2003). Vapour permeability should reflect soils close to the building foundation and soils which may be close to the foundations of future buildings. In general, this means that conservative measurements will reflect the near surface permeabilities (e.g. at depths less than 0.5 m) to be reflective of the most permeable layer near a slab-on-grade foundation. However, in some instances where more permeable layers may exist at a depth where there is potential for the building foundation to be located, this location must be measured.

Permeability measurements must be detailed enough to reflect variation across the entire area of interest and must be of sufficient quantity to capture natural variation in field sites. A minimum of 3 measurements are required for small sites with simple stratigraphy. Larger sites or more complex geology will always require more than the minimum number of samples. Where more than one layer exists across the site within the typical foundation depth, the zone with the highest permeability must be used in the Tier 2 estimate.

Conservative estimates of permeability must always be applied to the model. Where only 3 samples are available, the highest permeability measured must always be used as a model input.

Calculated Parameters

The total soil porosity, moisture-filled porosity and air-filled porosity can be calculated from the dry bulk density and water content as follows:

$$n = \frac{\rho_s - \rho_b}{\rho_s}$$

$$\theta_w = \frac{\rho_b M_w}{\rho_w}$$

$$\theta_a = n - \theta_w$$

Where:

n	= total soil porosity (cm^3 pore space per cm^3 soil)
θ_w	= water-filled porosity (cm^3 water per cm^3 soil)
θ_a	= air-filled porosity (cm^3 air per cm^3 soil)
M_w	= soil water content (g water per g dry soil)
ρ_s	= soil particle density = 2.65 g/cm^3
ρ_b	= soil dry bulk density (g/cm^3)
ρ_w	= density of water = 1 g/cm^3

θ_w cannot exceed n. When θ_w is equal to n the soil is saturated with water.

Where the default moisture content is being applied, but changes are being made to the bulk density and total porosity, the above equations can be used to estimate θ_w/θ_a for the default soil texture and this ratio can then be used to calculate a new value for θ_w and θ_a based on the change to bulk density.

TABLE C-1
PRIMARY TIER 2 ADJUSTABLE PARAMETERS AND ILLUSTRATIVE RANGES

PARAMETER	DEFAULT	ILLUSTRATIVE RANGE
Measured Parameters		
Bulk Density (g/cm^3)	c/g: 1.7 f/g: 1.4	c/g: 1.5 - 1.8 f/g: 1.3 - 1.6
Moisture Content (gravimetric) (M_w/M_s)	c/g: 0.07 f/g: 0.12	c/g: 0.03 - 0.15 f/g: 0.07 - 0.16
Organic Carbon Fraction (g/g)	0.005	c/g: 0.0005 - 0.007 f/g: 0.0005 - 0.03
Soil Vapour Permeability (cm^2)	c/g: $5x10^{-8}$ f/g: 10^{-9}	c/g: 10^{-6} - 10^{-8} f/g: 10^{-8} - 10^{-12}
Saturated Hydraulic Conductivity (m/y)	c/g: 320 f/g: 32	c/g: 32 - 3200 f/g: 0.032 – 32
Hydraulic Gradient (unitless)	0.028	0.001 - 0.1
Depth/distance to Contamination (m)[a]	0.3	0 – 10
Thickness of Contamination (m)[b]	3	0.5 - 5
Depth to Groundwater (m)[c]	3	0 – 10
Site Length (m) - parallel to GW flow	10	5 – 30
Site Width (m) - perpendicular to GW flow[b]	10	5 – 30
Distance to nearby surface water (m)[b]	10	0 – 300
Distance to potable water or agricultural water (m)	0	0 – 300
Calculated Parameters		
Effective Porosity	c/g: 0.36 f/g: 0.47	See note d
Water-filled Porosity	c/g: 0.119 f/g: 0.168	See note e
Air-filled Porosity	c/g: 0.241 f/g: 0.302	See note e
Distance from Contamination to Groundwater (m)[b]	0	See note f

c/g – coarse-grained soil
f/g – fine-grained soil
a – distance from the nearest point of the foundation of an occupied building
b – parameter only used in the calculation of leaching to groundwater and transport to nearby surface water bodies
c – depth below grade
d – calculated from bulk density, assuming soil particle density of 2.65 (see C.8.2)
e – derived from bulk density and water content (see C.8.2)
f – calculated from depth to contamination, depth to groundwater, and thickness of contamination

TABLE C-2
LINKED PARAMETER GROUPS

PATHWAY	PARAMETER GROUPS
Vapour Inhalation	*Group 1 – Soil Properties*[a] dry bulk density moisture content total porosity (calculated) air-filled porosity (calculated) water-filled porosity (calculated)
	Group 2 – Building Properties[b] building length building width effective building height depth to foundation base foundation slab thickness crack area crack length pressure differential air exchange rate
	Independent Parameters soil organic carbon fraction soil vapour permeability depth to contamination (soil objectives) depth to groundwater (groundwater objectives)
Groundwater Pathways	*Group 1 – Soil Properties*[a] dry bulk density moisture content total porosity (calculated) air-filled porosity (calculated) water-filled porosity (calculated)
	Group 2 – Source Dimensions source length (parallel to groundwater flow) source width (normal to groundwater flow) depth to contamination thickness of contamination depth to groundwater
	Group 3 – Hydrogeological Parameters saturated hydraulic conductivity hydraulic gradient
	Independent Parameters soil organic carbon fraction distance to receptor

a – Dry bulk density and total porosity are measured concurrently from the same sample. Moisture content is more problematic as it must reflect both spatial and temporal variability for the site. In practice, this measurement is difficult to assess and may require use of default parameters except in instances where samples are either from deep stratum that may be associated with consistent moisture contents or where use of more detailed monitoring protocols (e.g. use of moisture probes with long term monitoring) are employed.

b – Adjustment of building properties is not normally permissible at Tier 2, except to evaluate a building more sensitive than the Tier 1 default

– Groups of parameters must be adjusted together (i.e. if a site-specific value is used for one parameter, site-specific values must be used for all parameters in the group)

– Independent parameters can be varied individually based on site-specific data

APPENDIX D POINT-OF-EXPOSURE OR EXPOSURE PATHWAY MEASUREMENTS

Point-of-exposure or exposure pathway measurements of contaminant concentrations in appropriate media provide a means of increasing the realism and reliability of fate and transport modeling. Examples of such measurements are vapour-phase concentrations in soil gas and dissolved concentrations in groundwater at or near the contaminant source, at the point of compliance, or an intermediate point along the lateral transport pathway.

Although the use of exposure pathway measurements is a site-specific, data-based, technical procedure, the application of these measurements at Tier 2 differs from the use of user-adjustable parameters to calculate site-specific objectives. In the derivation of soil quality or remediation objectives, fate and transport modeling is used to establish a relationship between the concentration in soil at the contaminant source and the exposure concentration experienced by the receptor and, hence, risk. The relationship is used to determine the allowable source concentration or remediation objective corresponding to a target exposure concentration or risk. Adjusting assumptions used in the modeling would result in a change in remediation objective for the same target risk or health protection objective.

While exposure pathway measurements can be used to assist in the calibration of fate and transport models, they would not normally be used to recalculate soil objectives. Instead, they would be used in combination with modeling and long-term monitoring to ensure that existing contaminant concentrations in soil, water or air would not lead to exceedance of the target risk level, or health protection objectives. Depending on where point of exposure measurements are made, this involves a varying level of modeling either to back calculate appropriate concentrations at the point of measurement or to forward calculate time-dependant changes in concentration from the contaminant zone. Depending on the nature of the measurement, modeling of changes in the risk estimate with time will be a necessary component, particularly where the scenario is not in a steady state condition.

Point-of-exposure measurements are always conducted as part of more detailed site-specific risk assessment. Long term monitoring is always required for these approaches to verify the conservative nature of model predictions. In addition, these approaches may require more detailed assessment of all pathways and receptors, as outlined previously, where other pathways may become critical to overall risk.

Point-of-exposure or exposure pathway measurements are applicable with respect to the following pathways.

Indoor vapour inhalation

Three main processes govern the vapour inhalation exposure pathway: partitioning of a volatile chemical from soil or groundwater to the vapour phase; vapour phase transport from the contaminant source to the soil adjacent to the building foundation; and infiltration/dilution between the soil and the building air. The direct measurement of soil

vapour concentrations can reduce the uncertainty and conservatism in the generic modeling.

Modeling of the infiltration/dilution process is required to establish allowable vapour concentrations at the point of measurement that maintain the same protection level for receptors as adopted in Tier 1. Generic building assumptions are still required to avoid the necessity of land use restrictions. Other information will be required to support the use of point-of-exposure or exposure pathway measurements, including evidence that concentrations will not increase with time and that measurements are typical of the site-specific vapour concentrations expected from the contaminant of concern. In addition, where concentrations at depth are significantly greater than allowable Tier 1 concentrations, but are not generating significant concentrations at the building foundation, it may still be necessary to assess whether these concentrations result in other risks to receptors. For instance, risks for fire/explosive hazard, infrastructure impacts, aesthetic concerns, health of workers during excavation and construction etc may need to be re-evaluated for the contaminant of concern.

Depending on the site specific circumstances, the use of this technique may require implementation of a management plan to ensure materials remain at depth. This outcome would preclude the Tier 2 approach and require Exposure Control.

The modeling approach and relevant equations are presented in Appendix C.

Protection of potable groundwater, groundwater used by livestock and irrigation water

The Tier 1 soil guidelines for the protection of potable groundwater and groundwater used for livestock watering or irrigation are based on a simple leaching-mixing-dilution model that describes the relationship between the chemical concentration in soil and that in the groundwater directly beneath the site. At Tiers 1 and 2, the point of compliance for the protection of potable water is anywhere within the Domestic Use Aquifer. The measured chemical concentration in the groundwater at the location of greatest risk for groundwater contamination may therefore be compared directly with the groundwater remediation guidelines, thereby lessening reliance on the assumptions involved in the dilution modeling.

This approach is considered a site-specific risk assessment and is always accompanied by a requirement for increased data gathering and long term groundwater monitoring as supporting evidence to ensure that groundwater concentrations will not increase over time.

Protection of groundwater for aquatic life and wildlife watering

The derivation of Tier 1 values for the protection of aquatic life and wildlife watering utilizes lateral groundwater transport modeling with a default horizontal distance of 10 m which can be adjusted on a site-specific basis as described in the preceding section. Chemical concentrations measured in groundwater at the point of compliance or at any intermediate point along the transport pathway can be used to reduce the dependence on

modeling. This, however, is considered a site-specific risk assessment and is always accompanied by a requirement for a more detailed understanding of the contaminant zone and a requirement for long term monitoring to verify predictions.

Some modeling will still be required. For zones other than the point of discharge, it will be necessary to model the time-dependant changes in concentration from the contaminant zone to the point of discharge. For measurements at the point of discharge, it is necessary to model the time dependant change in concentration at the point of discharge based on information from the contaminated zone. Similar conditions apply as above regarding evidence of stable or declining concentrations.

Requirements for point of exposure monitoring

The use of point-of-exposure or exposure pathway measurements requires a scientifically defensible and consistent approach to sampling that ensures measured concentrations are representative of the appropriate point along the exposure pathway. In addition, modified modeling may be required to establish allowable concentrations at the measurement points. To ensure consistent application of this approach, specific sampling and modeling protocols are required. Since these are not presently specified in this document, point-of-exposure or exposure pathway measurements require progressing to more detailed site-specific risk assessments.

APPENDIX E DOMESTIC USE AQUIFER

The definition of a Domestic Use Aquifer (DUA) is given in Part A Section 2.5.2. This appendix gives guidance on how the sustained yield may be calculated to determine if the aquifer of concern meets the definition of a DUA and provides guidance on when the DUA may be excluded.

E.1 Determining Sustained Yield for Defining a DUA

For a geologic unit to meet the definition of a DUA, it must have a bulk hydraulic conductivity of 1×10^{-6} m/s or greater and sufficient thickness to support a sustained yield of 0.76 L/min or greater. Bulk hydraulic conductivities must be determined using pumping test or slug test information from a sufficient number of piezometers/wells completed within the unit of interest. Unit thickness can be determined using site borehole information, and data from the Alberta Environment Water Well Record Database.

To simplify the determination of a DUA, Figure 1 shows a boundary curve with the **minimum** thickness required to meet the DUA condition for confined aquifers plotted against hydraulic conductivity. Geologic units meeting the DUA conditions plot on or above the line. This graph was derived using the Q_{20} equation (Farvolden method) and a range of representative values for aquifer thicknesses and available head.

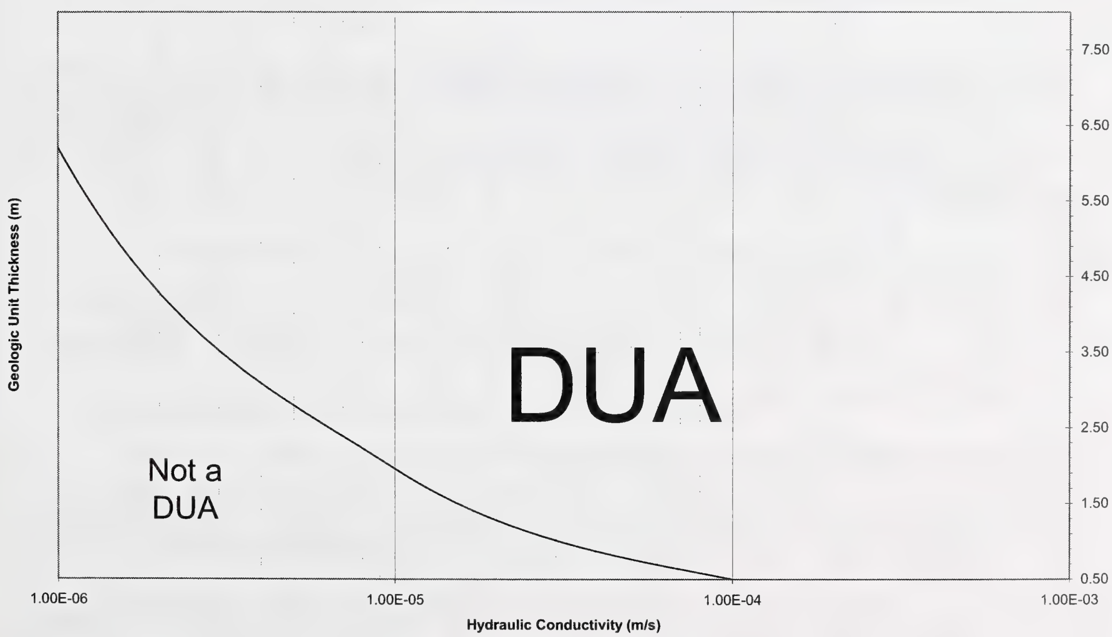

Figure 1. Relationship between geological unit thickness and hydraulic conductivity of a Confined DUA

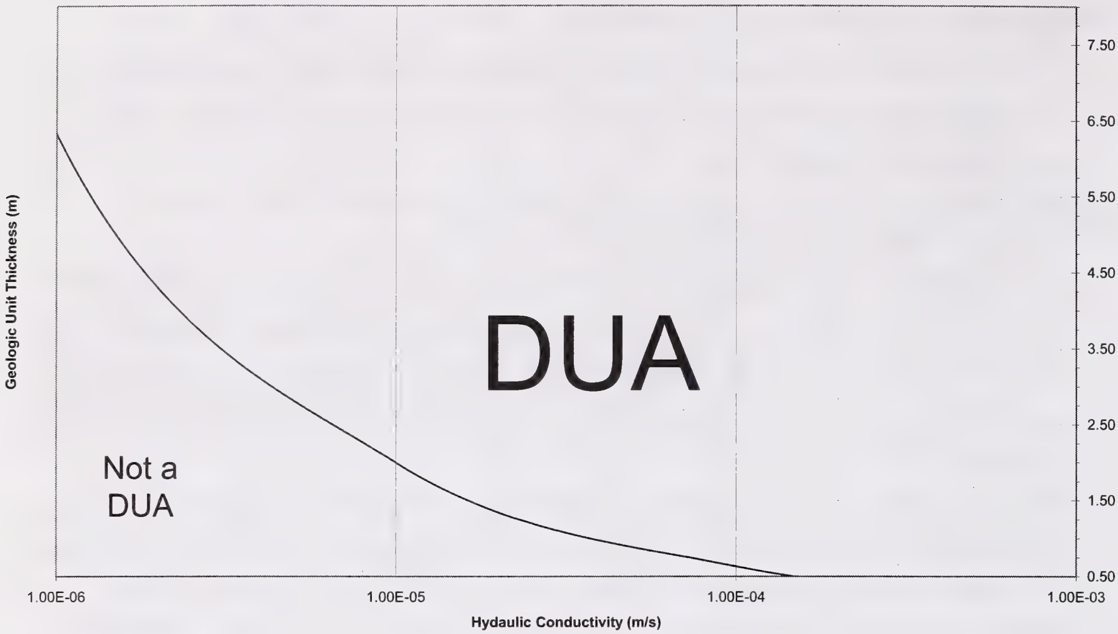

Figure 2. Relationship between geological unit thickness and hydraulic conductivity of a Unconfined DUA

Figure 2 shows a boundary curve with the **minimum** thickness required to meet the DUA condition for unconfined aquifers plotted against hydraulic conductivity. Geologic units meeting the DUA conditions plot on or above the line. This graph was also derived using the Q_{20} equation (Farvolden Mathod) and a range of representative values for aquifer thicknesses.

E.2 Exclusion of the DUA Drinking Water Pathway by Geologic Barriers

Under a Tier 2 approach, if there is sufficient thickness of natural geologic material, acting as a barrier between the contaminant zone and the DUA, the drinking water pathway may be excluded. The objective of this approach is to maintain drinking water objectives within the DUA.

To exclude the DUA pathway, there must be:

1. At least 5 metres of massive, unfractured fine-grained material meeting appropriate guidelines with a bulk hydraulic conductivity that is less than or equal to 1×10^{-7} m/s, or
2. An equivalent thickness of natural geologic material supported by technical information regarding the lithological properties prepared by the professional conducting the site assessment and accepted by Alberta Environment.

The conditions in (1) above apply to petroleum hydrocarbon contaminants. Exclusion of the drinking water pathway for other substances, such as salt, must be supported by technical information regarding the lithological and substance properties prepared by the professional and accepted by Alberta Environment.

E.3 Special Considerations

Interbedded Geological Units

For the purpose of the definition of a DUA, both single lithological units and interbedded geological units must be considered. Many of the bedrock units in Alberta are composed of deltaic deposits, which as a result of the depositional environment are lenticular and discontinuous. Therefore, these units should be considered a single hydrostratigraphic unit.

Geologic Units Containing Large-Diameter Wells

Shallow, large diameter wells, also know as "bored wells," are sometimes completed in geologic units that do not produce sufficient amounts of water to support a conventional water well. Typically, these geologic units do not meet the hydraulic conductivity or yield criteria for a DUA.

If large diameter wells are completed in a geologic unit that does not meet the hydraulic conductivity or yield criteria for a DUA, then the geologic unit should not be considered a DUA. In this case, the water well must be treated as a receptor, and must be handled using the Tier 2 Guidelines.

Exclusion of the DUA in a community with a by-law prohibiting the installation of water wells

Some communities and many municipalities have by-laws that prohibit the installation of water wells. This is considered an administrative control under the Exposure Control option. While it is possible to exclude the potential impact to the DUA in such circumstances, this does not meet the regulatory requirements of other Tier 2 options since it relies on an administrative control to ensure use of the groundwater is restricted. It is up to the proponent to ensure that the municipal activities and bylaws are consistent with the administrative controls under the Exposure Control option.

Exclusion of the DUA in for peat and muskeg deposits.

While it is possible that peat deposits and muskeg may meet the definition of a DUA, based on hydraulic conductivity and unit thickness, Alberta Environment does not consider peat deposits or muskeg to be a DUA because groundwater in them is unlikely to be used as a domestic source.

E.4 Calculation of sustained yield for confined and unconfined aquifers

For a geologic unit to meet the definition of a DUA, it must have a bulk hydraulic conductivity of 1×10^{-6} m/s or greater and sufficient thickness to support a sustained yield of 0.76 L/min (1.2667×10^{-5} m^3/s) or greater.

The long-term theoretical sustained yield is calculated using the **Farvolden Method**

$$Q_{20} = 0.68 * T * H_a * 0.7$$

$$T = K * b$$

Where:

- Q_{20} = the 20 year sustained yield (m^3/s)
- T = transmissivity of the geologic unit (m^2/s)
- K = bulk hydraulic conductivity (m/s)
- b = thickness of the geologic unit (m)
- H_a = available head (m)
- Q = well pumping rate during the pumping test (m^3/s)

For confined aquifers, the available head (H_a) is equal to the distance between the non-pumping water level in the well prior to the pumping test and the top of the aquifer.
For unconfined aquifers, the available head (H_a) is chosen to be 2/3 of the difference between the base of the aquifer and the non-pumping water level in the well (or 2/3 the saturated thickness).